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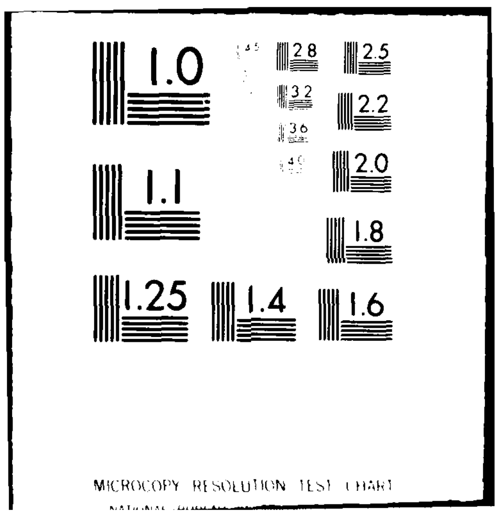
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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CAMBRIDGE, MASS. 02139

VORTEX-EXCITED VIBRATIONS OF MARINE CABLES

BY

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M.S. THESIS JUNE, 1976

SUPERVISED BY

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VORTEX-EXCITED VIBRATIONS OF MARINE CABLES

by

CHARLES HARRIS MAZEL

Submitted to the Department of Ocean Engineering, May 7, 1976, in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

A field study of the vortex-induced oscillations of 76.5' lengths of various marine cables was conducted. The test site, a sandbar at the mouth of Holbrook Cove in Castine, Maine, was chosen to insure uniformity of current over the entire test length. The flow of the incoming tide produced transverse vibrations of the test cable over a broad range of Reynolds numbers. Cable tension could be varied as desired. The amplitude, frequency, and general behavior of the cable motions were recorded. The results have been compared to the findings of previous investigators, and interpreted in the light of known properties of the body-wake interaction. A method of testing anti-strumming fairings is also presented, along with the results of such a test.

Thesis Supervisor: J. Kim Vandiver
Title: Assistant Professor of Ocean Engineering

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NOMENCLATURE

Re - Reynolds number, Vd/ν

ν - kinematic viscosity (1.3×10^{-5} ft^2/sec)

V - current speed, ft/sec

d - cable diameter under tension (≃ 75")

S - Strouhal number, fd/V

f_s - natural frequency at which vortices are shed

f_n - cable natural frequency

f_v - actual frequency of vortex shedding

f - observed frequency of cable vibration

f_1 - fundamental natural frequency

F - non-dimensional frequency, $(f/\sqrt{T})(2L\sqrt{m_V})$

δ - logarithmic decrement of damping

m_v - virtual mass per unit length

T - tension

ρ - fluid density

y - vertical displacement of cable

A - amplitude of vibration

L - cable length

CHAPTER I

INTRODUCTION

The problem of vortex-induced vibrations of marine cables, known as cable strumming, is one of present concern to those who work in the ocean. A great deal of money and effort is being expended to determine the exact causes and controlling features of the process, and to develop satisfactory means of preventing these vibrations. These motions, usually transverse to the incident flow direction and often of considerable amplitude, can lead to premature fatigue failure of mooring lines. Oceanographic data may be degraded when sensors are moving along with the cables to which they are attached. Hydrophones may pick up spurious pressure signals due to the acceleration of the instruments themselves. There is an increase in drag associated with the shedding of the vortices, and this means that more power and longer cable lengths are required to tow a submerged load at a given depth. The low-frequency motions may be an attraction to marine life, increasing the chances of "fish-bite" damage.

There are means of suppressing these vibrations, but they are often costly, and not applicable to all needs. Fairings, consisting of plastic strips that stream out behind the cable, can significantly reduce strumming, but of course add to the cost and weight of the cable. Drag is also increased, and there may be a problem winding these fairings on winches or passing them through sheaves. Optimum streamer lengths or amounts of coverage have not been adequately determined.

Basically, at Reynolds numbers of 40 and above, the separated flow behind a bluff object, in this case a flexible circular cylinder, rolls up into vortices which are then convected downstream in the Von Karman vortex street. Above about Re = 300 these vortices form asymmetrically, rolling off each side of the cylinder alternately. There is a lift force produced due to the pressure differential between the two sides of the cylinder resulting from the asymmetry. The fluctuating force produces vibrations in a direction transverse to the fluid flow. In the case of cables, these motions commonly reach peak-to-peak amplitudes of up to two diameters.

Rigid objects such as pilings are also subject to these forces. Large circular piles used in the construction of a deep-water jetty off Immingham, England, vibrated at significant amplitudes during periods of tidal flood, requiring design modifications to provide additional strength [37]. Above water, the same process is responsible for Aeolian tones, vibrating transmission lines, and damaging oscillations of tall smoke stacks in a strong wind. Vortex trails have even been observed in satellite photographs of cloud formations downstream of mountain peaks on ocean islands [3].

There is an extensive literature in the field of vortex shedding. Most experiments have been conducted in wind tunnels or small water channels. Cylinders tested have usually been smooth, and most often fixed rigidly in place. When vibrating cylinders were tested, they were again usually short lengths, either driven sinusoidally or spring-mounted. Most of the attention has been paid to the wake that is formed behind the cylinder. In short, there has been a near-total lack of data garnered from observation of a long length of flexible cable. Data from the few cases that have been studied are hopelessly complex due to non-uniformities of current and tension over the span of the cable.

The present experiment was designed to help fill this experimental gap. It was intended to be a field test of as long a cable as possible, while still satisfying the experimental restrictions of constant tension and uniform current. Such an experiment would more closely approximate true ocean conditions than could be achieved in a laboratory. Emphasis would be on characterizing the response of a number of cables subjected to varying, but known, experimental parameters, and upon refining techniques of acquiring accurate data under field conditions. The data could then be compared to the laboratory and full-scale results. In addition, a means of easily determining the effectiveness of anti-strumming fairings was devised.

CHAPTER II

BACKGROUND

2.1 Rigid Cylinders

Since the early recording and elucidation of the basic nature of the vortex shedding process by Strouhal [38], Rayleigh [33], and Von Karman [43], there has been a great deal of study, both theoretical and experimental. For smooth, stationary cylinders the process is fairly well understood. The frequency at which the vortices are shed can be determined from the relationship $f_s = SV/d$, where S is the non-dimensional Strouhal number, V is the flow speed, and d is the cylinder diameter. S is primarily a function of Reynolds number. Roshko [35] investigated the process for Re up to 10^4. Below Re = 40 vortices are formed simultaneously on both sides of the body. At higher Re, vortices form and are shed alternately from each side of the cylinder. Associated with the shedding is a pressure differential across the cylinder which results in a lift force, transverse to the flow, at the same frequency at which the vortices are shed. In addition, there is a fluctuating drag force at twice the shedding frequency. The magnitude of these forces has been measured by many investigators, in both wind and water tunnels [4,13,14,27,34].

In the range $300 < Re < 10^4$, Roshko found the vortex wake to be irregular, with frequency components in a finite bandwidth about a predominant shedding frequency. Throughout this range the Strouhal number is approximately constant at S=.21. The shedding frequency is thus directly proportional to the flow speed. His measurements have since been verified and the results extended throughout the sub-critical Re range, up to Re = 2×10^5 [4,7,13,14,27]. A plot of S vs. Re can be found in Figure 1. Vortex shedding has been noted at higher values of Re, but with a great deal of scatter in the measurements [19]. In addition, effects of turbulence, surface roughness and non-circular cross-section have been investigated [2,7,15, 27,36].

Although the shedding frequency everywhere along the span of a cylinder is determined by the Strouhal relationship, there may be little or no spanwise correlation of the phase and amplitude of the shed vortices. Some studies have found the vortex filaments to be straight, but inclined to the cylinder axis [6,21,35], but this is not universally the case.

2.2 Oscillating Cylinders

The case for cylinders which oscillate is very different. The transverse motion of the cylinder imposes a correlation of the shedding along the span. The shed vortex filaments are parallel to the cylinder. Lift and drag forces are amplified, and increase with increasing amplitude of vibration.

Most of the experiments performed on vibrating cylinders

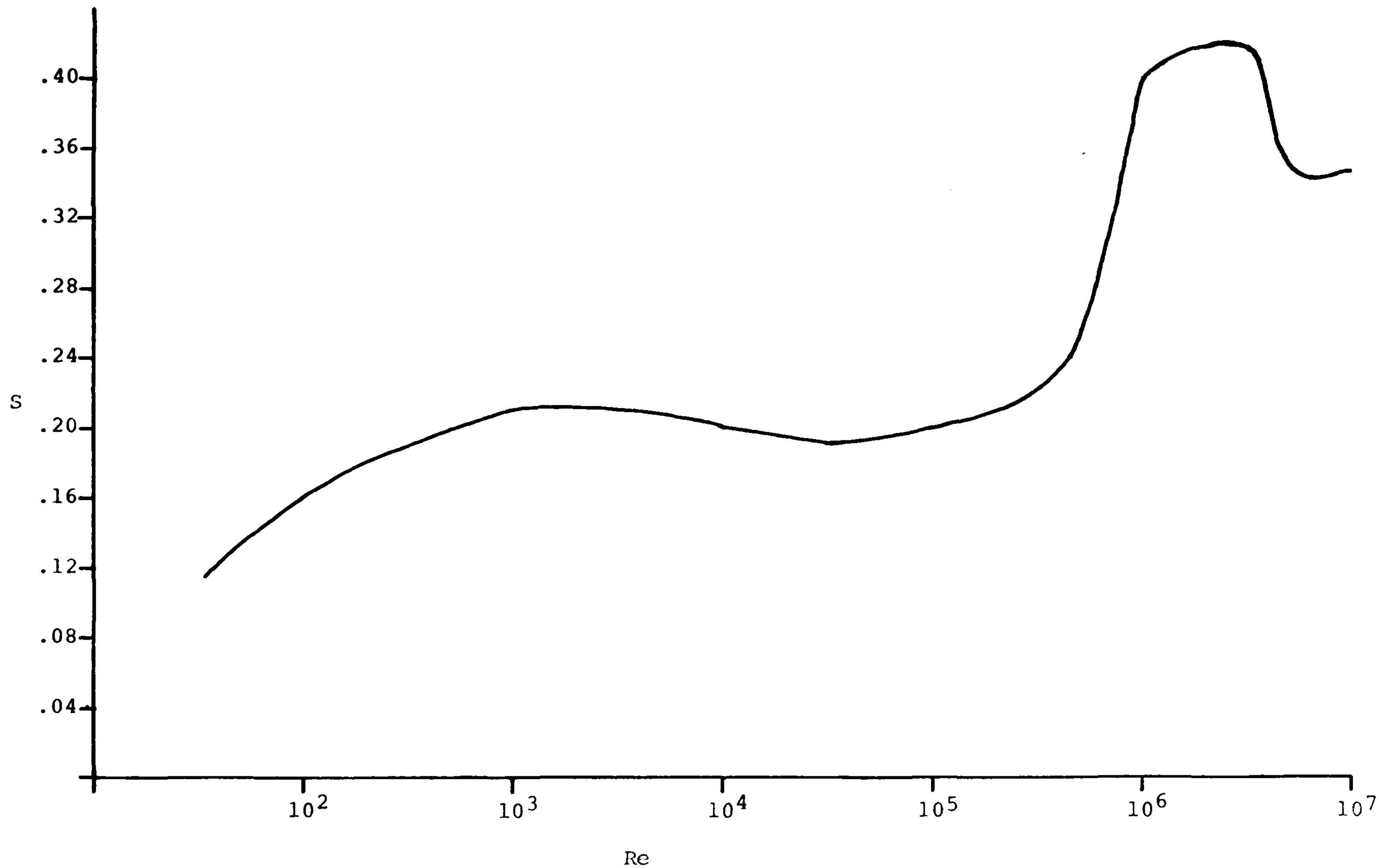


Figure 1. Strouhal # vs. Reynolds # (from King, et al. [20])

have utilized short, rigid cylinders driven externally [5,21, 22,39,40]. The usual procedure is to hold flow speed constant and vary the driving frequency, while measuring lift and drag forces and observing the characteristics of the vortex wake. A smaller number of studies have utilized rigid cylinders which were free to vibrate, either spring mounted at the ends [13,27], cantilevered [20,42], or mounted in a pivoted arrangement [28]. Griffin [16] conducted an experiment specifically to verify that the free and driven approaches produced the same results. Only a very few experiments have been performed on flexible cylinders [6,8,29,30,31,32], either cables or elastic tubing.

The same general behavior has been observed by all of the experimenters. The interaction of the cables or cylinders and the wake is that of a non-linear self-excited oscillator. For cables and spring mounted cylinders, the lift and drag forces and vibration amplitudes show marked peaks when the natural frequency of vortex shedding, f_s, coincides with the natural frequency of body vibration, f_n. The response decreases as the two frequencies are moved apart. Driven cylinders also show a peak in lift and drag forces when the wake natural frequency and the driving frequency coincide.

Over a range of f_s around f_n, however, the actual vortex frequency, f_v, will remain at f_n. The vibration causes the vortex shedding process to synchronize, or lock in, with the body motion. The range over which this occurs has been found to be as great as ±25% of the body frequency [5,13,21,22,39]. The actual extent of the lock-in range is dependent on the amplitude of vibration, being wider for greater amplitudes. The lock-in bandwidth also increases with decreasing damping. Griffin [32] and Koopman [21] have found that there is a minimum amplitude, on the order of 0.1 diameters, below which lock-in will not occur. The peak displacement amplitudes commonly observed for cables and spring mounted cylinders are in the range of .5 to 1.0 diameters, well above the lock-in threshold. At the end of the lock-in range, the wake frequency jumps to the f_s associated with the flow conditions.

For a flexible cable vibrating at the second mode, Ramberg and Griffin [32] observed that at the antinodes, where the cylinder motion exceeded 0.1 diameters, the shedding was entirely at the cable frequency. At the nodes the shedding was entirely at f_s. In between, the record showed varying components of both frequencies.

The synchronization of vortex shedding along the span results in increased lift and drag forces. As mentioned above, there is a sharp peak at coincidence of f_s and f_n, with amplitudes trailing off as f_s moves away from f_n, even though f_v remains at f_n. When the wake is not locked in a beating behavior is often observed, the two component frequencies being f_n and f_v. It has also been found that f_v may have a value which is between the f_s expected and the body frequency f_n [1,5,40].

When f_v is locked in to f_n, the motion is said to be self-excited. This term is used to describe vibrations for which the input force only exists by virtue of the body motion [11]. In the case of vortex shedding there would be a force whether there was lock-in or not, but it would be very different in the two cases. Di Silvio [12] terms the motion self-controlled to capture the distinction.

There is no clear statement in the literature as to how to determine f_s, the natural shedding frequency for vibrating cylinders. The Strouhal number of .21 for stationary cylinders does not apply to all cases. In almost all presentations of data, it is noted that the peak amplitudes, either of vibration or lift force, occur at a frequency which is less than the frequency predicted using S = .21. Most authors do not deal with the issue explicitly, and it is necessary to pick values from their plotted data. For example, in the paper by Tanida, et.al. [39] the peak lift forces occur at $f_v d/V = .17$ at Re = 4000. In addition, the non-lock-in points plotted follow the same relation. It would be expected that the peak forces would occur when the natural, or preferred, shedding frequency is coincident with the body natural frequency. Other authors find similar results for the peak forces [5,6,13,16,20,22,28, 30]. Some do find peaks where $f_v d/V = .21$, but there is definitely not the consistency associated with the stationary cylinder Strouhal number. King et.al. [20] do discuss this issue briefly.

Griffin and Ramberg have been the principal experimenters with marine cables [16,29,30,31,32]. They are concerned primarily with resonant vibrations. Vickery and Watkins [42] equated the energy input to the cable per cycle (assuming a sinusoidal forcing function) with the energy dissipated by damping at resonance and found that the amplitude was primarily dependent on the dimensionless group $m_v\delta/\rho d^2$, where δ is the log decrement of free vibration of the system. Griffin uses this in the form of a response parameter $S_G = 2\pi S^2\left(\frac{2m_v\delta}{\rho d^2}\right)$, where S is the Strouhal number for stationary cylinders. The peak amplitude at resonance is found to be dependent on S_G, with a threshold at $S_G = 4.0$. For higher S_G the vibration will not exceed 0.1 diameters, the minimum amplitude for lock-in [29]. The data found in the present experiment will be compared to Griffin's results in this framework. Griffin makes no predictions related to possible amplitudes when the system is not at resonance.

There have been a number of review articles on vortex shedding [3,23,24,25], which serve as a useful guide to the state of knowledge of the subject and the prime questions of interest. In addition, a number of attempts have been made to formulate mathematical models which correlate with experimental observations [12,17,18,27,41].

2.3 Suppression of Shedding

Numerous methods have been tried to prevent cable strumming. The usual approach is to change the flow characteristics by adding streamer-type fairings to the cable. These can be effective, but they have the disadvantage of increasing drag. Addition of splitter plates or helical strakes behind a cylinder has been attempted by Roshko [36] and others [2,8,15, 42]. Depending upon the configuration, the attempted fix may suppress the shedding entirely, reduce it in amplitude, or even shift it in frequency. A faired cable was tested in the present experiment.

CHAPTER III

BASIC THEORY

A taut cable can, as a first approximation, be modelled as an ideal string. Assuming no damping, the corresponding wave equation is $T\frac{\partial^2 y}{\partial x^2} = m\frac{\partial^2 y}{\partial t^2}$. The natural frequencies of this system are $f = \frac{n}{2L}\sqrt{\frac{T}{m}}$, n = 1, 2, 3,.... The corresponding modal shapes are $y = A\sin\frac{n\pi x}{L}$. The inclusion of damping would mean only a slight shift in the calculated frequencies.

For vibrations in water, the added mass must be taken into account. The theoretical added mass coefficient of a circular cylinder is 1, meaning that the added mass is equal to the mass of the displaced volume of water. This was the number used in calculating m_V for the cables. There is evidence [29] that the added mass is essentially independent of wavelength, frequency, and amplitude of vibration, in the range of interest here, and is the same in still and flowing fluid. The validity of using the string model was checked by comparing predictions for the fundamental mode in air and in water to actual observations. The fit was found to be close. The mode numbers referred to in the discussion of experimental results were found using the ideal model as a basis.

The use of the string equation neglects the bending stiffness of the cable. This is a good approximation for the low modes, where the curvatures are small, but for the higher mode shapes the effect of stiffness becomes more important and will cause the observed natural frequencies to be higher than calculated by the simple string equation. Such effects were observed in this experiment.

CHAPTER IV

THE EXPERIMENT

4.1 Previous Work

This experiment grew out of the preliminary tests conducted by Jessup and Davis as a part of the 1974 Ocean Engineering Summer Laboratory, which is conducted yearly in Castine, Maine, in cooperation with the Maine Maritime Academy. They attempted to procure quantitative data on cable vibrations. Their experimentation with various motion transducers led to the design of the "fish", described below. As stated in their report [9], they worked first with cables 250 yards long, stretched from shore to shore across a sandbar at the entrance to Holbrook Cove. The data from this set-up were difficult to interpret, so they attempted to isolate a 50 foot test section by using chains to link a cable of this length to lengths of synthetic rope which ran up to shore. The rope was tied to trees at both ends, with a winch and strain gauge tension-measuring device at one end. The test section was maintained at a constant depth of submersion by a float and anchor system. This permitted the experimenters to position themselves behind the cable in a boat and reach into the water to make measurements.

The present experiment was a refinement of the previous one, both in terms of instrumentation and cable deployment. A problem with the earlier approach was that one could not really be sure that all of what you were seeing on the records was due to behavior of the test section alone. Changes in tension due to vibration of the supporting ropes outside the test length could be transmitted longitudinally to the test section. The current would clearly not be the uniform over the entire immersed length.

4.2 Experimental Set-Up

The real aim of this experiment was to obtain reliable qualitative and quantitative data on an intermediate length of cable, intermediate in that it would be much longer than laboratory samples and yet more tractable than a full-scale system. Comparisons would be made between the results of this field test and the many laboratory tests on stationary or oscillating, rigid or flexible cylinders. This required a known length of cable in isolation, maintained at a known tension in a known uniform current. It meant providing a stable, independent support system so that appreciable tensions could be applied with no ties to shore.

The sandbar at the entrance to Holbrook Cove was again selected as the test site, since it offered shallow depths at high tide, proximity to the shore base, a dry platform at low tide for setting up the test cable, and long spans of approximately uniform current. This latter feature was verified by current measurements made before the actual test site was selected. In addition, the current speed varied over a wide range during the course of a tide, providing a corresponding range of Reynolds numbers. Runs were made only on incoming tides, and current speed varied from a high of about 2.3 feet per second (.70 meters/second) when water first spilled over the sandbar, to a low of 0 at slack tide. A photo of the sandbar can be seen in Figure 2.

Once the test site was selected the cable mounting system was established as in Figure 3. A test length of 76.5' (23.3 meters) was marked off. At either end of this section three 10-foot (3 meter) sections of steel pipe were embedded at an angle in the clay bed of the sandbar, using a water pump to create a concentrated water jet for clearing a path. All of the pipes were sunk so that no more than a few inches protruded above the level of the bar. This was important since there was frequent boat traffic into and out of the cove, and nothing could be fixed in place; it would constitute a hazard to navigation when we left the site each day.

The outer two pipes at each end took up the tensile load, which was divided between the two pilings by a short length of connecting cable. The actual tensions used were in the range of 100 to 600 pounds. Shorter sections of pipe were slipped into the tops of the inner pipes and locked in place with a bolt. A sheave, fastened near the top of each of these insert

Figure 2. Photograph of experiment site.
Sandbar in center.

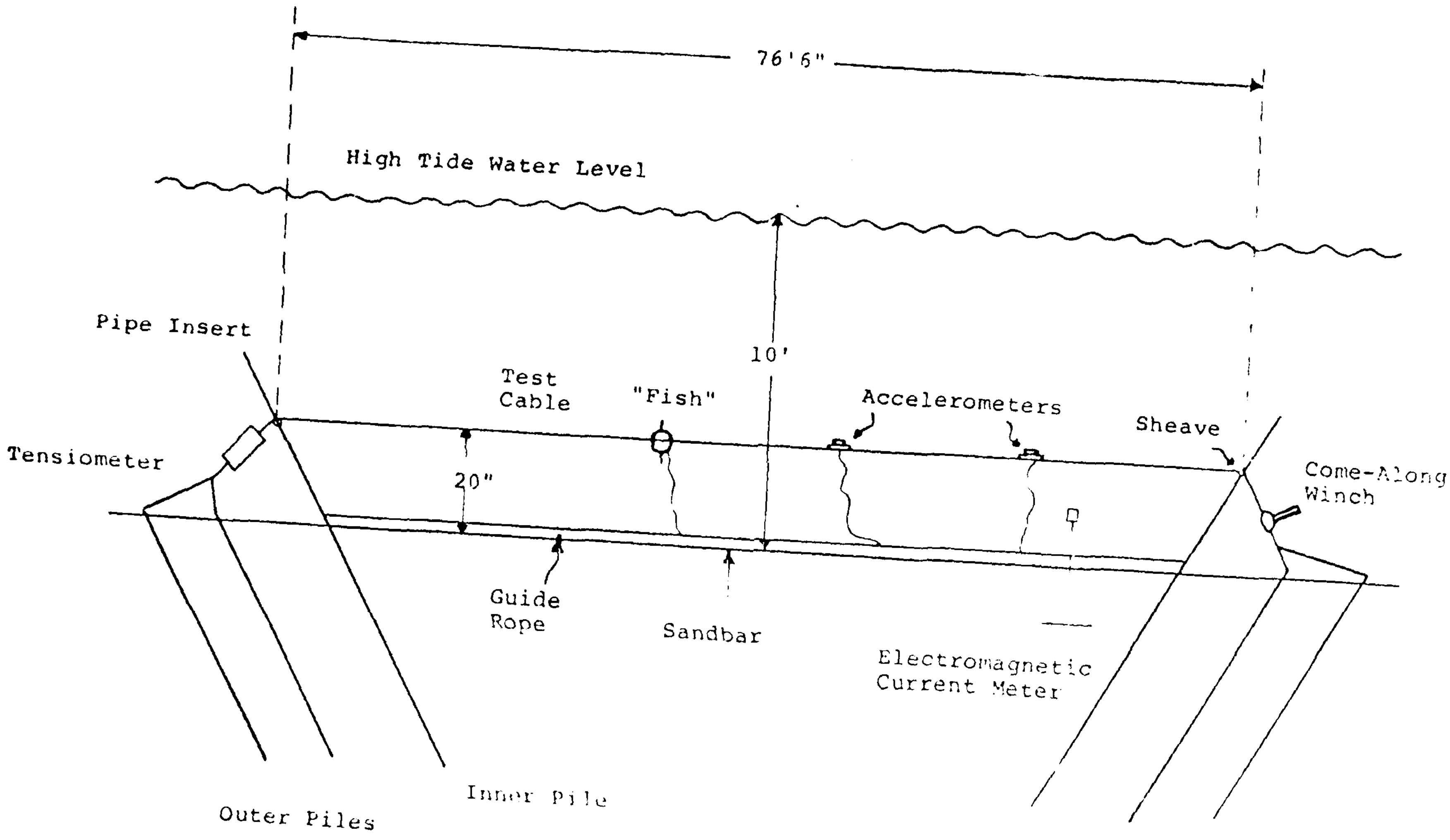


Figure 3.--Test cable support arrangement.

pipes, supported the test cable.

In practice, setting up the site each day started with a bare sandbar, with only the piles permanently out on the site. Upon arriving at the sandbar, the inserts were secured in place, and the day's test cable laid out from one end to the other, passing over the sheaves at each end. An additional length of rope was fastened between the bases of the support piles. The instrument signal cables were secured to this line. This guide rope was also used as a hand-hold for divers venturing out along the cable while the current was running at high speed.

A tensiometer was shackled in line between the support rope and the test cable at the west end of the site. A zero reading was taken on the tensiometer before initial tensioning occurred. A come-along winch fastened between the east end of the test cable and the support posts at that end served to adjust the tension. The tension could be varied at any time during the experiment by sending a swimmer into the water to operate the winch.

Once the cable was tensioned the accelerometers were fastened in position and the signal wires run along the guide rope and into the boat. The boat, a 17-foot (5 meter) open craft with an outboard motor, was always moored at the east end of the site. It was held in position by an anchor securely wedged under a rock off the bow, with a second off the stern to prevent sideways motion. A safety line was also tied to the support posts to insure that the boat would not be carried rapidly away in case the bow anchor failed.

This arrangement positioned the cable about two feet above the sandbar, out of range of any boundary layer effects. The cable set-up required about 30 minutes, and was timed so that at completion the first water was flowing over the sandbar. Next the electromagnetic current meter was placed in position, and lastly, just when the water reached the level of the cable, the "fish" was fastened to the cable. Once all signal wires were led back aboard the boat the set-up was complete. Buoys were placed in the water to mark the cable position for passing boats.

The actual run of the experiment consisted of recording intervals of data -- current meter, tensiometer, "fish" and accelerometer outputs -- as the tide ran its course. Continuous recordings were not made, as this would have provided a surplus of data, much of it redundant. Instead, the current was monitored for changes, and data were taken for short periods of time at frequent intervals. At times the tension was changed rapidly by keeping a swimmer in the water, taking about 30 seconds of data at one tension setting, and then having him change the tension. The intent of this was to determine the effect of changes in tension at a constant current speed. This required that the procedure be run rapidly, as the current itself varied fairly quickly. Another test was a traversal along the cable of one accelerometer, while leaving the other in a fixed position. A diver or swimmer was required to swim along the cable, moving the accelerometer to predetermined positions. This would hopefully give some insight into the extent of spanwise correlation of the cable behavior. Did the entire cable act as a unit, or did localized areas respond independently?

At slack tide, when the cable stopped vibrating, divers entered the water to disassemble the experiment, which was now covered by 10 feet (3 meters) of water. This procedure was essentially the reverse of the set-up, and posed no great difficulty. On one occasion the experiment was taken down with the current running at 1.5 knots, an operation which required caution since the current was difficult to swim against for extended periods. Upon completion of disassembly all that remained at the site were the tops of the support posts poking out of the sandbar.

4.3 Summary of Cable Data

The cables tested were a jacketed wire rope, a jacketed Kevlar fiber rope, and a polypropylene and polyester synthetic rope. Details on all of these ropes can be found in Table 1, along with the range of experimental conditions to which they

TABLE I

SUMMARY OF CABLE STRUMMING DATA

	Sampson Blue Streak	Wire Rope	Phyllistran	Anti-Strumming Kevlar w/w.o. Fairing*
Measured diameter under tension (inches/cm)	.39/1.0	.275/0.7	.485/1.2	.154/0.4
Specific gravity	1.2	2.8	.95	1.3
Linear density in air (slugs/ft)/(g/m)	$2.0\times10^{-3}/93.5$	$2.3\times10^{-3}/108.3$	$2.4\times10^{-3}/113.2$	$.34\times10^{-3}/16.1/.31\times10^{-3}/15.0$
Added mass per unit length (slugs/ft)/(g/m)	$1.7\times10^{-3}/79.5$	$.8\times10^{-3}/147.8$	$2.6\times10^{-3}/122.8$	$.24\times10^{-3}/12.0/.24\times10^{-3}/12.0$
Construction	12-strand single braid, polyester & polypropylene	3 x 19 torque balanced galvanized plow steel, with plastic jacket	7 x 7 "Kevlar" with polyurethane jacket	Braided polyurethane impregnated Kevlar, with 3 twisted conductors down center
Breaking strength (lbs)	5000	4000	17000	2000
Current range (ft/sec)	0.3-2.1	0.4-2.4	0.3-2.2	1.5-2.1
Reynolds number range	660-5200	360-4200	800-6850	1500-2100
Frequency range (Hz)	1.3-11.3	2.2-18.3	1.5-12.1	14.3-21.3/19.0-27.8
Strouhal number range	.16-.18	.16-.18	.20-.22	.12-.13†/.17
Tension range (lbs)	70-230	60-580	110-450	65-80
Typical amplitude (diam)	.4-.7	.4-.7	.3-.5	.5†/.5-.7

* Fairing: 1/16" synthetic fuzz woven helically into Kevlar braid
† Based on unfaired diameter

were subject. They are representative of cables in common use in ocean applications.

4.4 The "Fish" Transducer

Details on most of the instruments used can be found in the Appendix. The "fish" is described at greater length here, since it was developed specially for this project.

The fish (hereafter referred to without quotation marks) measures displacement directly, and thus yields records which are easier to interpret than those of the accelerometers. The design of the fish grew out of the earlier experimental work of Jessup and Davis. They tried numerous methods, such as motion pictures and sonar, of recording cable motions. Their greatest success was achieved with what was probably the simplest method of all. They sealed a rotary, linear potentiometer into a PVC cylinder with the shaft protruding through an O-ring seal. An arm was attached to the shaft. The other end of the arm was fastened to the cable under study. One of the experimenters held the unit fixed in position behind the cable. The vertical displacements of the cable caused rotation of the potentiometer shaft, yielding voltage fluctuations directly proportional to the displacement of the cable.

The fish is an improved version of this method, and does not require a person holding the unit in position. A photograph of the fish behind a cable can be seen in Figure 4. Figure 5 is a drawing of the fish, showing details of construction. Basically, the fish provides a stable platform for a 50KΩ rotary potentiometer. The unit is neutrally buoyant and trimmed in pitch. The connecting arms attach to the potentiometer shaft protruding from one side of the fish, and ride in a hole drilled as a bearing in the other side. The parallel arms prevent twisting of the unit.

Drag forces cause the fish to seek an equilbrium position behind the mean location of the cable. Thus no external adjustments are necessary to accommodate changes in mean position due to variations in cable catenary, which can occur whenever current speed or cable tension change. The fish can follow these slow changes in position, but cannot respond to the rapid cable vibrations produced by the vortex shedding process. The fish sits still while the arm translates vertically, varying the voltage output of a simple divider circuit. An op-amp voltage follower is located inside the sealed fish body. The three wires required for power, signal and ground emerge from the tail of the fish, and enough slack is allowed so that the wires do not influence the fish position.

The frequency response of the fish was determined in the small water tank in the Ocean Engineering laboratory. Tests showed, and observations in the field confirmed, that the fish response was steady for higher frequencies. At lower vibration

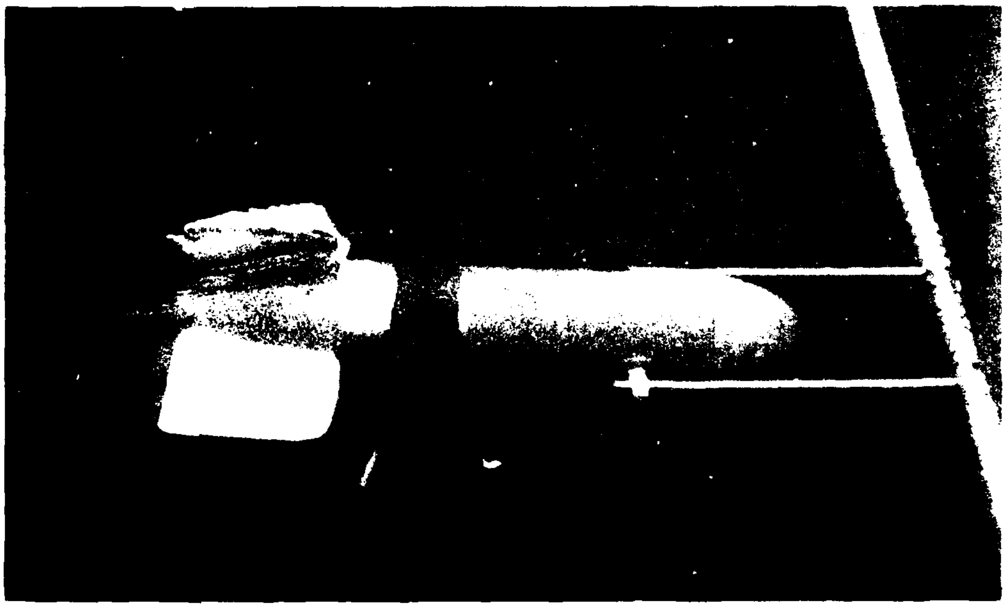


Figure 4. Photograph of fish in position behind cable.

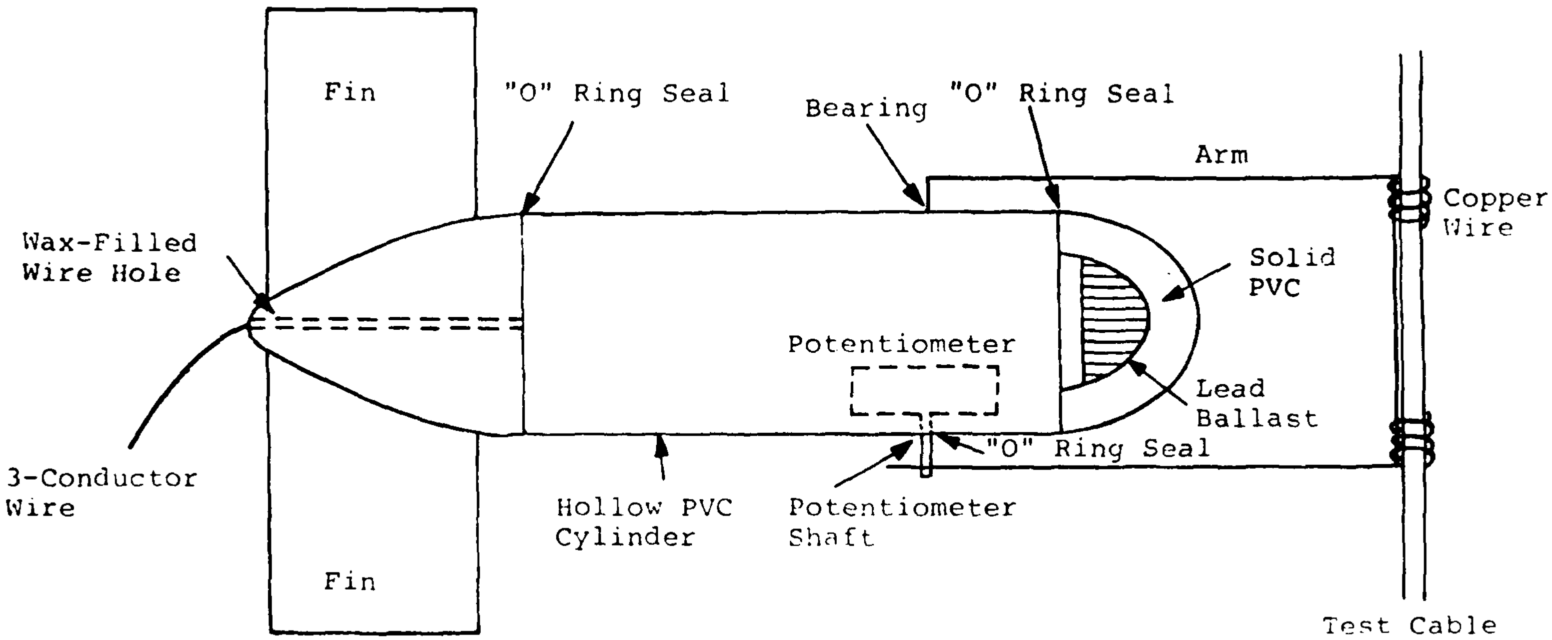


Figure 5. Construction of the "fish", the direct displacement transducer.

frequencies, on the order of 3 to 4 Hz and below, the fish tended to follow the cable motions, with some phase lag. In the field, these low-frequency motions occurred when the current was the weakest, which in turn meant that the drag forces on the fish were also small. Friction in the O-ring shaft seal and the potentiometer then caused the fish to move. In addition, surface wave motion influenced the position of the fish when the depth of submersion was small.

The voltage output of the potentiometer is a direct record of the motions of the cable. Spectral analysis of the fish and accelerometer records consistently revealed the same frequency components in the vibration record, attesting to the performance of the fish. The sensitivity of the unit is 1.52"/volt (3.86 cm/volt). Samples of the fish output can be seen in many of the figures. Improvements are now being worked on, in order to make the fish easier to construct, and to improve its low-frequency response.

CHAPTER V

RESULTS

5.1 Analysis

All data were played back onto a Beckman Type S-II Dynograph 4-channel strip-chart recorder, providing a visual time history of all of the test runs. A sample of the record thus obtained is shown in Figure 6. These charts were first examined visually. At periodic intervals, chosen to provide a reasonable characterization of the cable data, frequency was determined by counting vibration peaks over a known period, and current and tension readings were obtained from their respective traces. The numbers thus obtained were used to calculate the observed Strouhal number fd/V, the Reynold's number Vd/ν, and the non-dimensional mode number $F = f2L\sqrt{\frac{m_v}{T}}$. F is the ratio of the observed frequency f to the calculated fundamental frequency at that time, $\frac{1}{2L}\sqrt{\frac{T}{m_v}}$. This had to be recalculated for nearly every point since the tension changed so frequently. The amplitudes were calculated from the fish records, and a qualitative description of the response behavior was noted.

In addition, numerous sections of the record were analyzed on a Ubiquitous Model UA-15A Spectrum Analyzer. It should be noted that the best way to get a feel for the actual behavior of the cables is to go over the strip-chart recordings, and observe how the cable behavior shifts in response

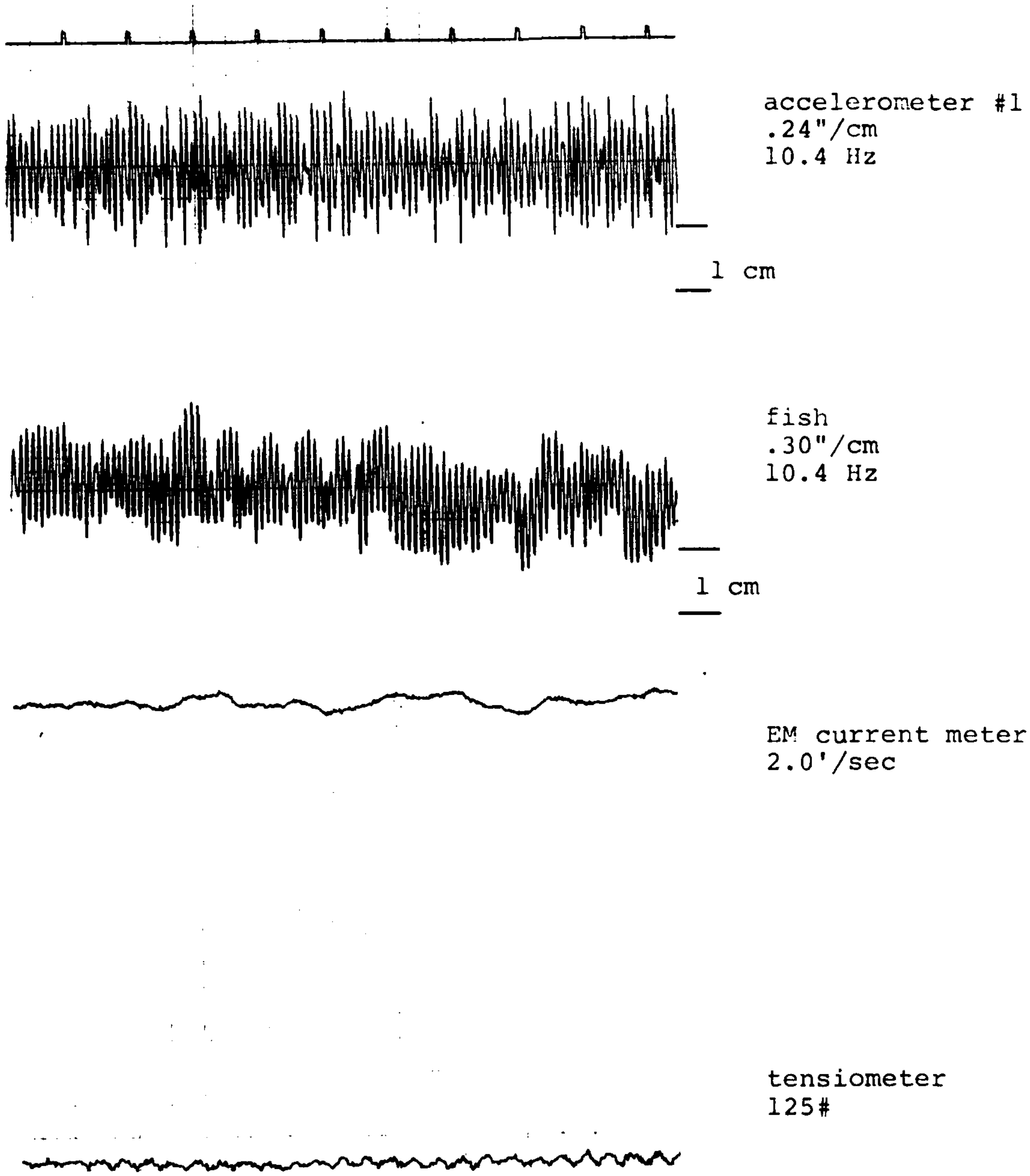


Figure 6. Sample of strip-chart recording of transducer outputs. Blue Streak.

to changes in experimental conditions. A tabulation of the data taken for each cable is presented in the Appendix. The time history listing gives the points in the order in which they occurred. A computer program was written to sort the data on the basis of any desired parameter as an aid to interpretation. These tabulations will be referred to as the data are discussed.

5.2 Behavior

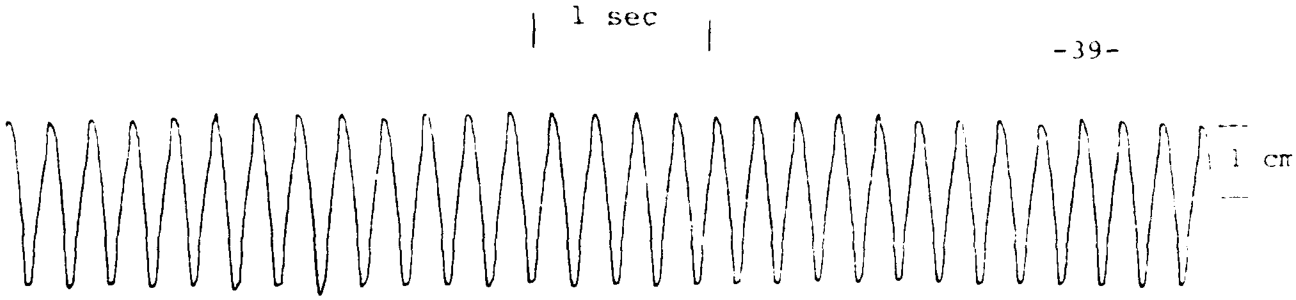
Most of the vortex shedding characteristics observed in laboratory tests were found, or at least indicated, in the behavior of the test cables. It should be noted that only the cable amplitude and frequency were measured here, while most of the laboratory studies included hot-wire measurements of the shed vortex frequency. These two frequencies are not necessarily the same, as discussed earlier. If the driving (vortex) frequency is close, but not exactly equal to, a resonant frequency of the cable system, the dominant response could be at the cable natural frequency, due to the mechanical amplification of the system. The bandwidth of the shedding process is not infinitesimally small, so there is energy being input over some range of frequencies. Proximity to a resonant frequency will influence the response. In this light, three major regimes of cable behavior could be distinguished: resonant lock-in, non-resonant lock-in, and non-lock-in.

Resonant Lock-In

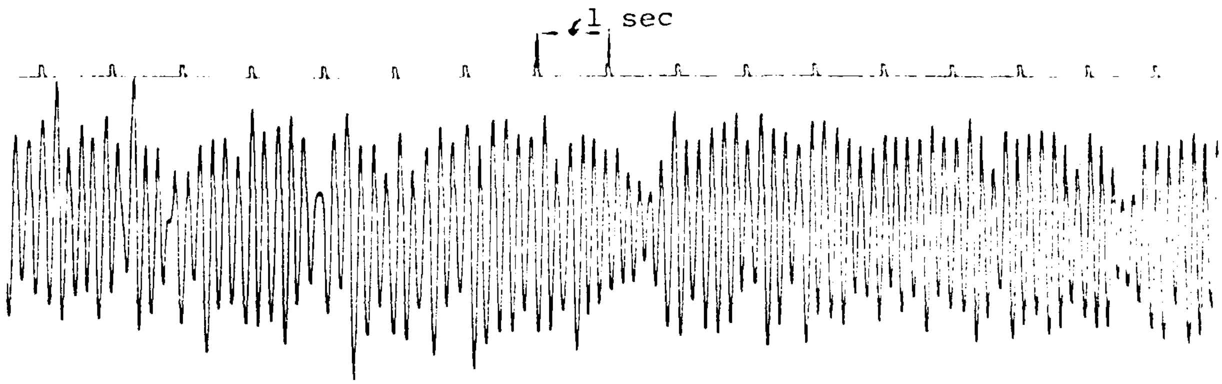
Resonant lock-in is characterized by extremely stable motion of the cable, as exemplified by the strip-chart recording in Figure 7a. The cable displacement is clearly sinusoidal, and the amplitude remains essentially constant. As expected, the spectral analysis of such a section shows a single sharp peak at the frequency of vibration, as in Figure 8a. It is postulated that this behavior occurs when the natural shedding frequency corresponds within a few percent to a mechanical resonance of the cable. The driving and response peaks are at the same frequency, and the result is a motion in which the input energy matches the energy dissipated by damping, producing stable conditions. Even in the rapidly changing conditions encountered in the field, this behavior sometimes persisted for several minutes. All of the cables tested showed a greater tendency to lock in to the lower modes (one - four) than to the higher ones.

Non-Resonant Lock-In

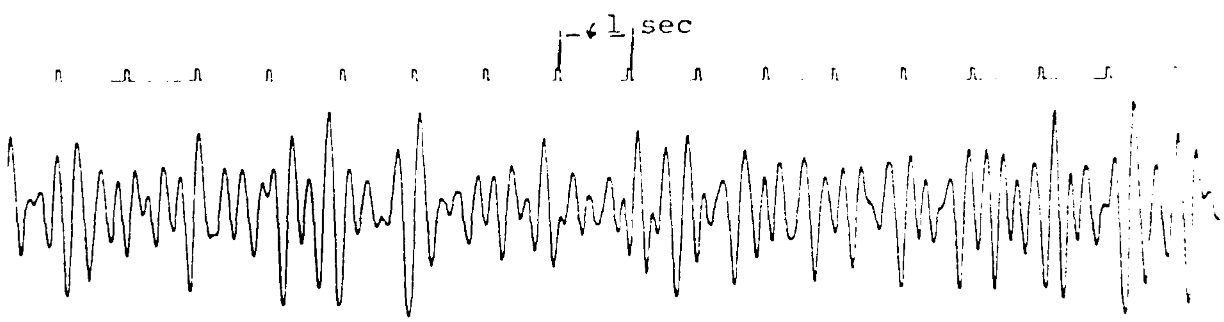
A sample which would be termed non-resonant is illustrated in Figure 7b. The motion in this case is not as steady as that of the resonant lock-in, but there is a fairly easily determined mean amplitude, and the motion is again nearly



a) Resonant lock-in. Wire rope. Tension: 360 lbs, current: .6 ft/sec, 4.2 Hz. Displacement .152"/cm on trace. Second mode.



b) Non-resonant lock-in. Blue Streak. 175 lbs, 1.2 ft/sec, 5.75 Hz, .152 "/cm on trace. Fourth mode.



c) Non-lock-in. Blue Streak. 170 lbs, .8 ft/sec, 3.9 Hz, .152"/cm on trace. Between second and third modes.

Figure 7. Representative samples of "fish" record for types of cable behavior.

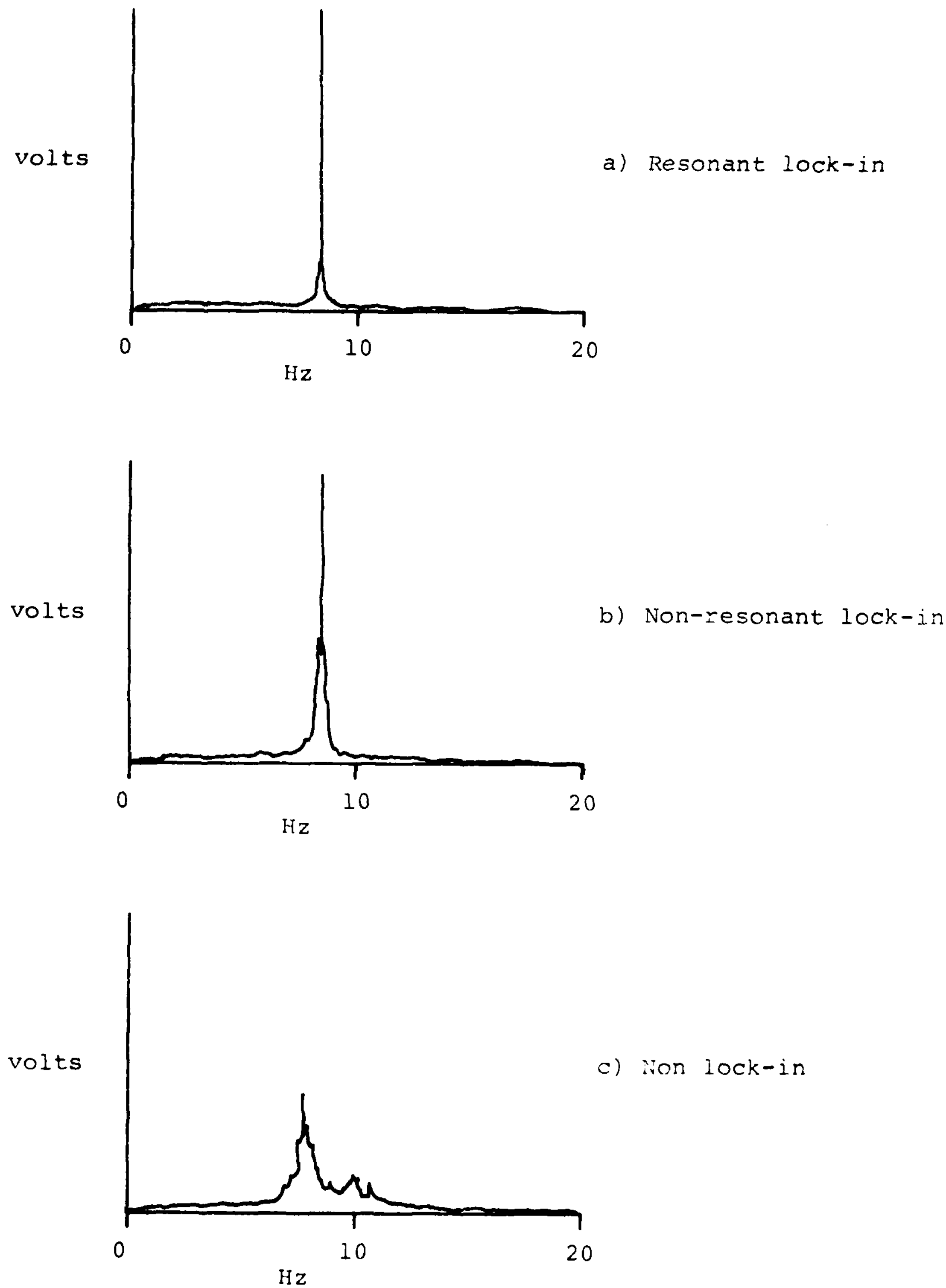


Figure 8. Samples of spectrum analyzer output.

single-frequency, with a spectral bandwidth only slightly broader than that for resonance (see Figure 8b). There is no apparent regularity to the fluctuations in amplitude, and no apparent beating effects.

The distinction between resonant and non-resonant behavior was emphasized at times during the experiment when the tension (and therefore the natural frequency) was constant and the flow velocity varied slightly. A current shift of only a few percent was observed to be sufficient to induce a marked change from regular to unsteady motion, or vice versa. Remembering that no wake measurements were made, it is postulated that this behavior occurs under conditions of forced synchronization of wake and cable frequencies. That is, the natural shedding frequency, f_s, is not coincident with the natural cable frequency, but the amplitude of vibration is sufficient to impose synchronization and f_s is within the lock-in range. Random instabilities are then probably responsible for the observed irregularities of behavior. Simultaneous cable and wake measurements would be required to verify this.

Non-Lock-In

Under non-lock-in conditions, as seen in Figure 7c, the amplitude fluctuations are severe. It is expected that this occurs when f_s is far from a cable resonance, and the resulting motion is controlled by the shedding process. It must be noted that a vibration amplitude greater than 0.1 diameters was found by other investigators to be a necessary, but not a sufficient, requirement for lock-in to occur. Thus it is quite feasible that vortices could be shed at f_s while the cable responded at f_n. Indeed, records with clear beating were often observed, as seen in Figure 9. The component frequencies were the cable natural frequency and the frequency of vortex shedding. The spectral record of a non-lock-in section can be seen in Figure 8c. There is a peak at the observed vibration frequency, but the bandwidth is much greater than for the other two modes of behavior.

In all three modes of behavior the motion appears to be consistent along the span of the cable. Simultaneous measurements at widely spaced points produced similar records. Although transient differences may have appeared occasionally, there was no substantive difference. At times an accelerometer near one of the support posts would show a strong component of the second harmonic of the strumming frequency. This seems to be an end effect, as it was verified that this component weakened rapidly as the instrument was moved away from the post. It seems reasonable to conclude, therefore, that the entire span of the cable was experiencing similar motions at any given time.

The preceding was a general behavioral description of the observed cable vibrations. In what follows additional evidence

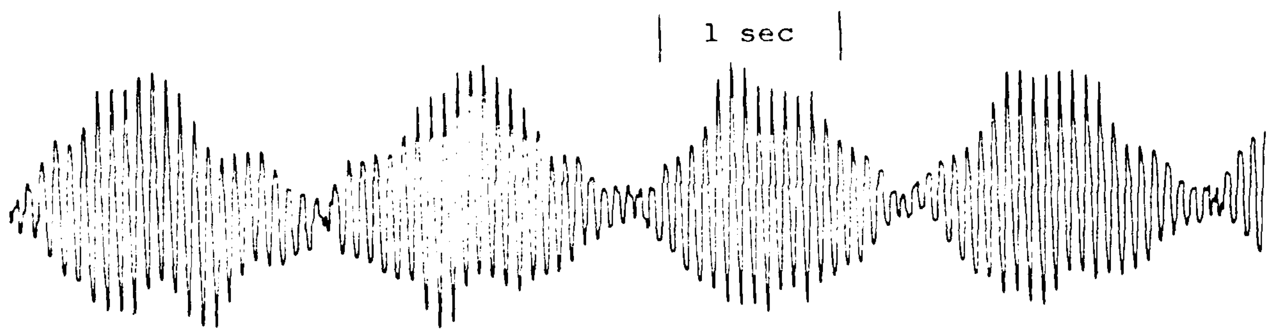


Figure 9. Pronounced beating. Wire rope at 180 lbs tension.
Current: 1.9 ft/sec, displacement: .152"/cm on trace.
Component frequencies: 13.1 and 13.7 Hz.

for the categorization will be provided, along with quantitative results. It must be noted that there is a certain degree of subjectivity involved in the assigning of records to one class or another. At times the behavior was borderline between two of the modes. For example, the amplitudes might not have been really constant, but the records may have shown none of the strong fluctuations associated with a non-resonant section.

5.3 Phase Information

During nearly every run, one of the accelerometers was traversed over as much as 20 feet (6 meters) of the cable span, in short hops. At each stop a short record was taken. The observed pattern of the records provides support for the breakdown made above. If a taut cable is vibrating at its n^{th} natural frequency, there will be $n - 1$ nodes along the span (not counting the forced nodes at the posts). On opposite sides of each node there will be a 180° phase shift in the displacement. This pattern was found for cables vibrating resonantly or non-resonantly. The signals from the stationary accelerometer or fish and the traversed accelerometer were either exactly in phase or 180° out.

It is necessary to remark, however, that no actual nodes were found, either by divers observing the cable in the water, or in the instrument outputs. The exact reason for this is not known. If a 180° phase shift does occur, as was clearly observed, it must be associated with a nodal point. It is possible that some process is causing the location of the node to be unstable, so that no single point will remain stationary over an extended time. Spurious travelling waves of small amplitude could also hide the existence of nodes, and yet still allow the dominant behavior to be observed by the phase relationships along the cable.

Under non-lock-in conditions, no such consistent pattern was found. Comparing the outputs of two transducers reveals only a constantly shifting, and apparently random, phase relationship. This is similar to the observations of stationary cylinders or non-locked-in cables in the laboratory.

5.4 Amplitude

The observed amplitudes can be found in the tables in the Appendix, and are plotted in Figures 10 through 12. A number of points should be kept in mind when examining these values.

i) All data are taken from the recordings of the fish, the direct displacement transducer. Since the accelerometer output is proportional to $a\omega^2$, small vibration components at harmonics of the predominant strumming frequency produce large signals. Interpretation would require spectral analysis and subsequent integration of the areas under the peaks. In cases where the accelerometer signal was predominantly a single frequency, the calculated amplitudes compared well with the results from the fish. In order to be consistent and avoid misleading results the accelerometer was used only as a check on the fish records.

ii) The flow, and therefore the vibration characteristics, changed continually. The amplitude data were selected from records that had exhibited a steady vibration behavior for a sufficient length of time to insure that transition from one type of vibration to another was not occurring. Within these steady sections the amplitude was estimated from that portion exhibiting the highest average response over many cycles. This was intended to present a worst-case behavior.

iii) No corrections were made for the position of the fish along the cable. This would not be expected to make a great deal of difference under non-lock-in conditions where no stable mode shape would be expected. Under resonant conditions, however, the position of the sensor could be highly important if the cable took on a true sin $\frac{n\pi x}{L}$ mode shape over the entire cable length. As mentioned above, no stable nodes were observed. Attempts to scale the data by a factor taking into account the fish position did not produce a smoothing of the data.

It is clear both from the three graphs, and from the tabulations in the Appendix sorted by amplitude, that the largest amplitudes tended to be associated with resonant vibration behavior, although these were not greatly different from the amplitudes of observed non-resonant behavior. The smallest amplitudes were generally found when the cable was not locked in. This is the result that would be expected on the basis of the laboratory studies. Coincidence of the forcing frequency and the natural frequency of vibration leads to the largest response. The uncorrelated, unsteady shedding when the driving frequency is outside the synchronization range leads to lower average power flow into the cable, and therefore lower average response.

The resonant amplitudes were generally on the order of 0.5 diameters, non-resonant 0.4-0.5, and non-lock-in 0.3-0.4. Within these regimes, the wire rope showed the greatest amplitudes (and the strongest tendency to lock-in), followed by the Blue Streak and then the Kevlar. The differences among the cables will be discussed later. Although the non-lock-in sections had the lowest mean amplitudes, the greatest individual cable excursions did occur at these times.

There is a fair degree of scatter in the plotted data points. This is no doubt partly attributable to the fact that the study was conducted under constantly changing field conditions, with known but uncontrollable experimental parameters, and not under strict laboratory control. For the resonant and

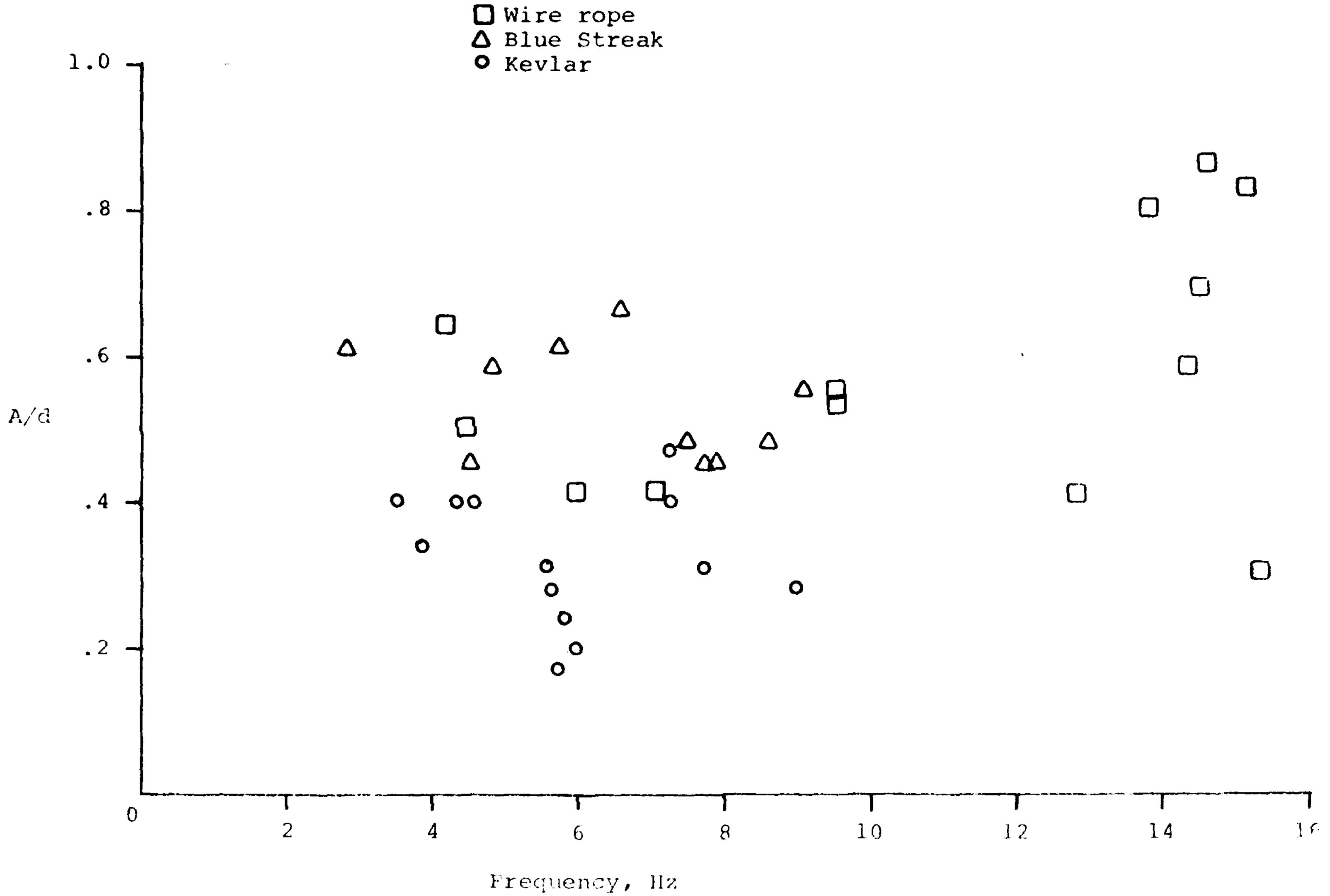
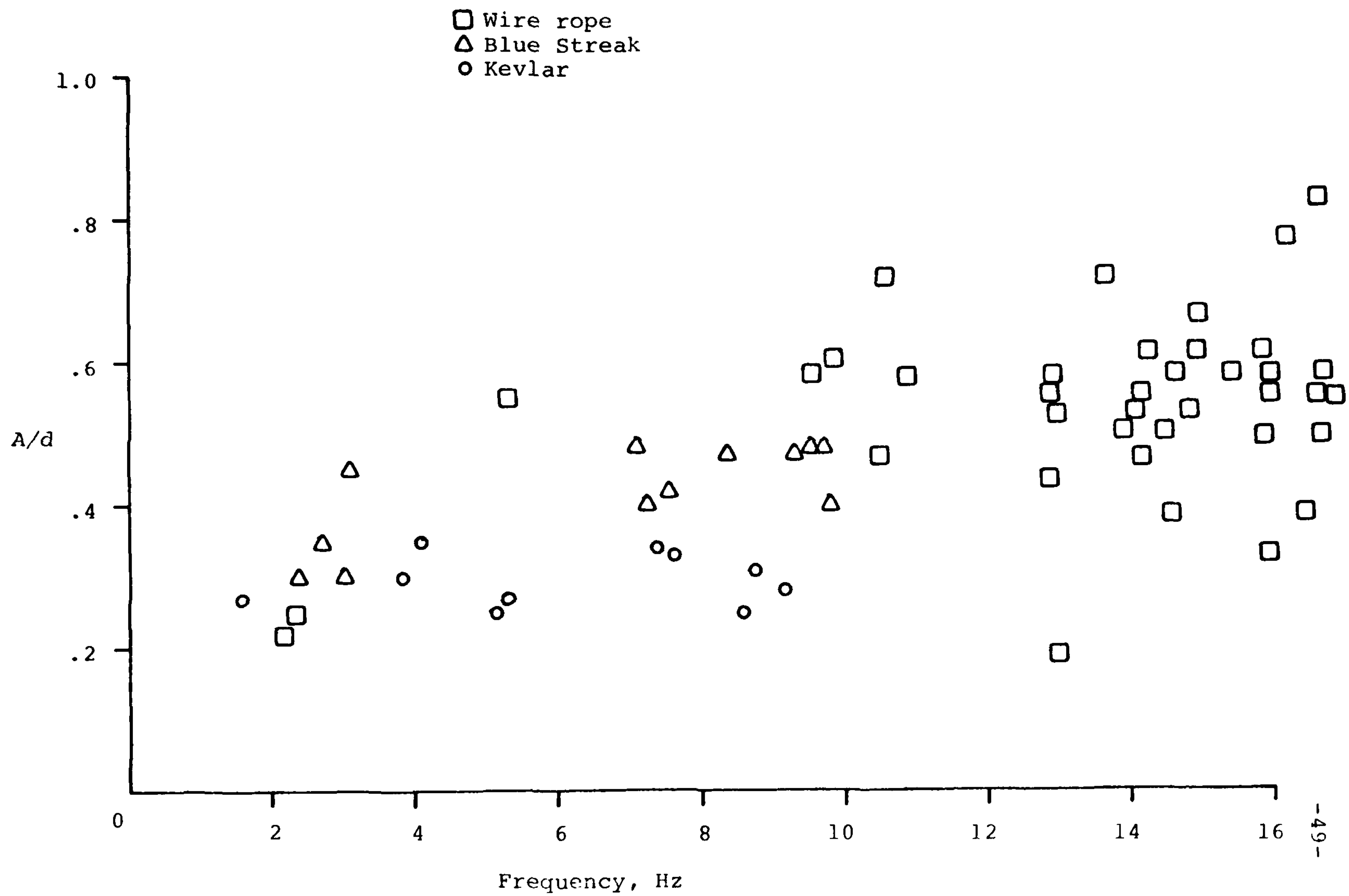


Figure 10. Resonant lock-in. Amplitude vs. frequency.



Figue 11. Non-resonant lock-in. Amplitude vs. frequency.

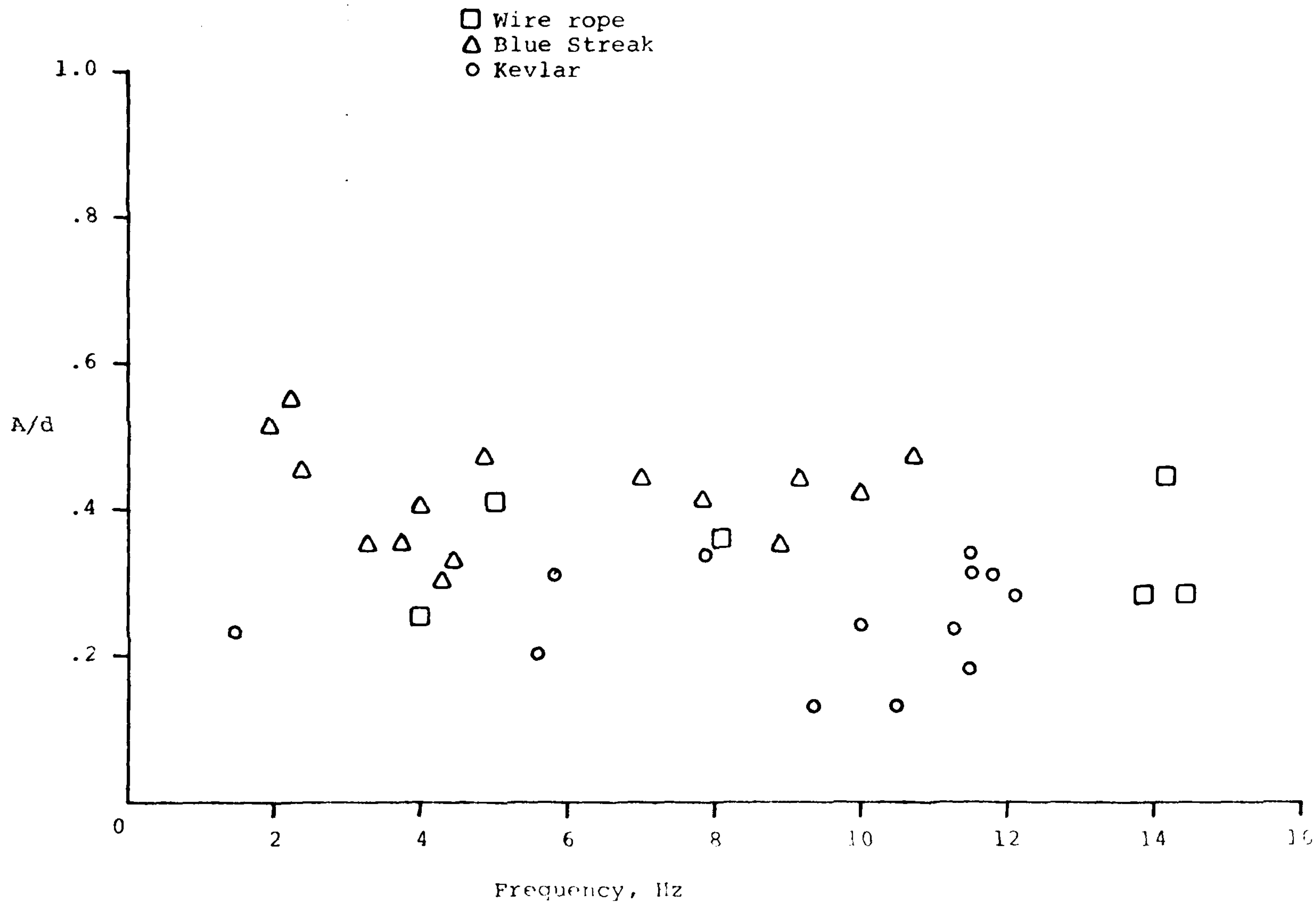


Figure 12. Non lock-in. Amplitude vs. frequency.

non-resonant results there is also the question of transducer position along the cable span. The points plotted also represent a wide range of vibration modes, depending on the tension at the time of measurement. Thus, two data points at the same resonant frequency may represent vibrations at two entirely different mode numbers. Whether frequency or mode number is the more important determinant of the maximum amplitudes that can be achieved remains to be determined. The modal damping no doubt has a governing influence.

5.5 Tension Variation

At times during the experimental runs the tension was varied rapidly by sending a swimmer to operate the winch. This would have the effect of shifting the natural frequency, and thus altering the interaction between shedding frequency and cable frequency. In many cases a small shift in tension produced a noticeable change in cable behavior. This is essentially equivalent to holding the tension constant and allowing current speed to change naturally. Figure 13 shows the effect of such a tension change, with the behavior going from resonant to non-resonant. The record reads from left to right in time. Initially, the behavior was resonant with the tension at 165 pounds. A drop to 155 pounds tension led to the non-resonant behavior at the right side of the trace.

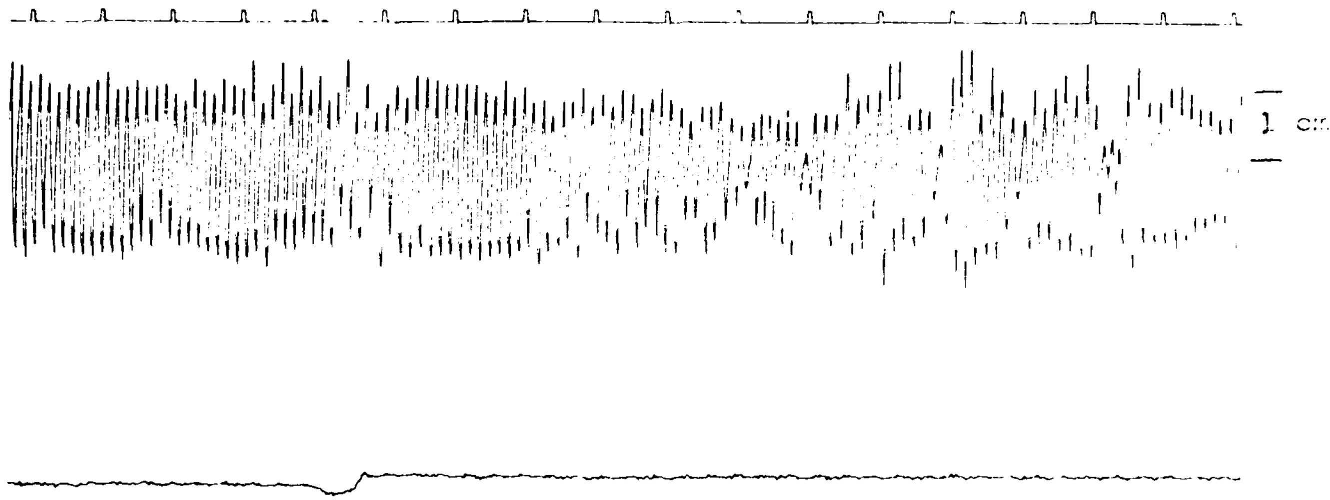


Figure 13. Effect of tension variation. Tension decreases from 165 to 155 lbs. Current 1.3 ft/sec, 7.25 Hz. Displacement .152"/cm on trace.

The time covered by the record is about 20 seconds, during which period the current did not change.

5.6 Mode Numbers

In examining the tabulation of results sorted by behavior, it can be seen that there is a tendency (in this experiment most conclusions are drawn from trends of overall observations) for the resonant behavior, at least at the lower frequencies, to be associated with exact multiples of the fundamental frequency (whole values of F). That is, the cable is responding right at a natural frequency. Non-resonant points are generally associated with frequencies close to natural frequencies. If there is true lock-in, whether resonant or not, the cable would be expected to be vibrating at a natural frequency. Small discrepancies could be due to various errors in determining F, such as errors in estimates of virtual mass, in tension measurements or departures of actual natural frequencies from the values predicted by the ideal string equation. Non-lock-in behavior tends to occur at frequencies comfortably between modes. Notice that sometimes non-lock-in behavior appears to be associated with whole number values of F. It is possible for the wake and cable frequencies to be entirely different, as mentioned previously. This could result in the cable responding at its natural frequency, but unstably since the driving force is highly irregular. Further work must be done to throw more light on this.

5.7 Observed Strouhal Numbers

Figure 14 is a plot of observed Strouhal number, fd/V, versus Reynolds number for the cables tested. Both the Blue Streak and the wire rope had values generally around .16 to .17. Kevlar, on the other hand, seemed to follow quite a different pattern, with Strouhal values on the order of .22 to .23. The reason for this difference is not yet known. It seems to be too large to be accounted for by any systematic error in the recording of the data.

Of particular interest is the range of Strouhal numbers encountered for each cable. If there were no natural frequencies involved, and the shedding frequency simply tracked the changes in velocity, an essentially constant value of observed Strouhal number would be expected, determined solely by the factors controlling the vortex-formation process. If lock-in occurs, however, as in reality, a different situation should result. Over some range of current speeds the frequency will remain constant at the natural frequency. When the velocity is below the value that would produce shedding at f_n, the frequency locks up to a higher value than would appear if there were no synchronization. This would result in a Strouhal num-

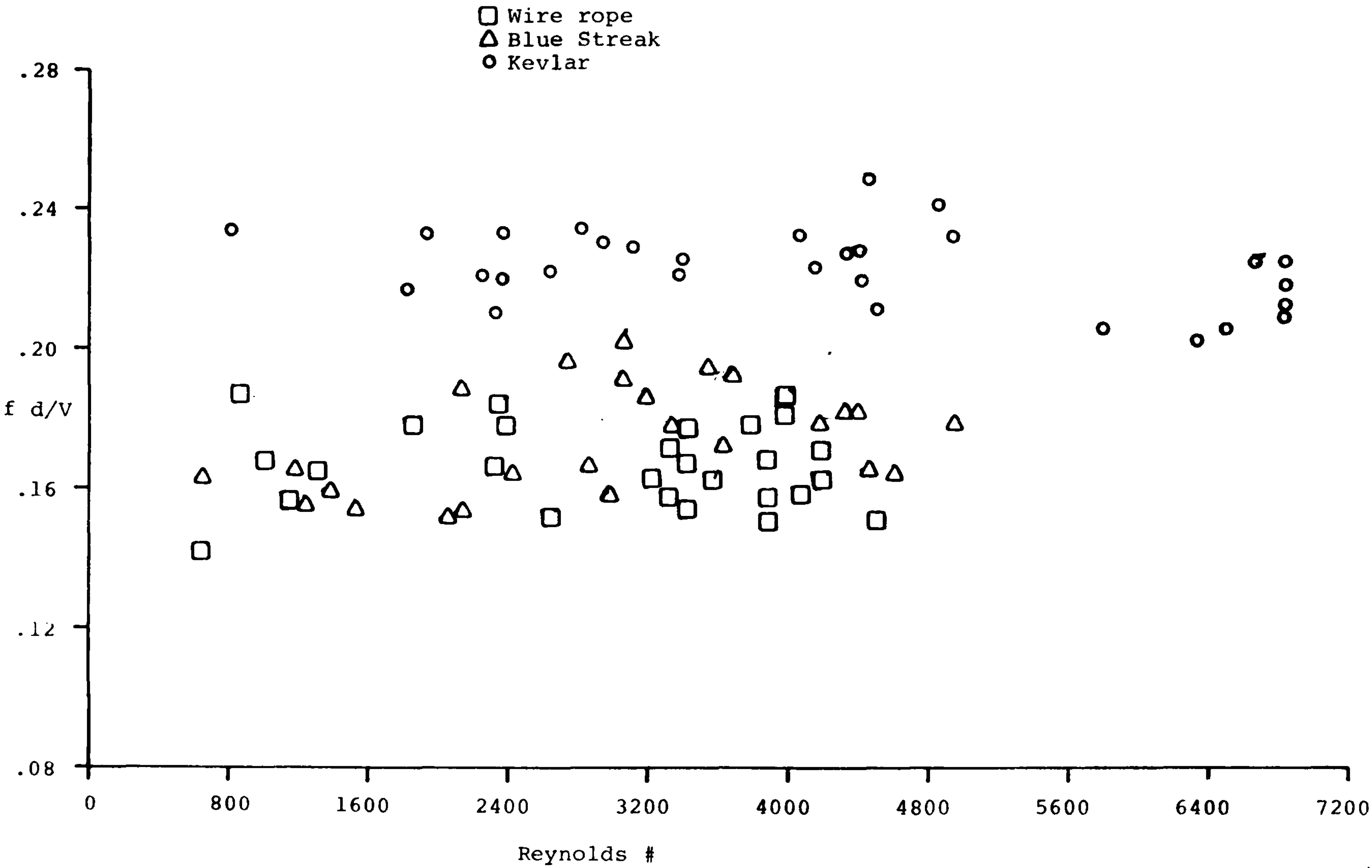


Figure 14. Observed Strouhal # (fd/V) vs. Reynolds #

ber greater than the mean values. Conversely, if the frequency locks down from a higher value, a lower observed Strouhal number would result.

In fact, examination of the data indicates (again, a tendency) that this variation in fd/V does occur, and that the "abnormal" Strouhal numbers occur when the cable is vibrating at a mode number close (within $\pm.2$) to resonance. This is not a hard and fast rule, and there are many exceptions. It would be expected that the motion should be non-resonant at those times, but that is not always the case. The limits of the measured values, .14 to .18 for Blue Streak and wire rope, .20 to .24 for Kevlar, point to a lock-in range of somewhere between 15 and 20% of the natural frequency. There is not enough data to make more definitive statements on this subject.

5.8 Accuracy

Some leeway in interpretation must be allowed for experimental error. More detail on the instruments and their behavior can be found in the Appendix, but some of the relevant points will be mentioned here.

The electromagnetic current meter used is sensitive to current changes on the order of .01 feet per second. However, due to a relatively crude calibration procedure, the actual sensitivity of the device (that is, the actual voltage per foot per second of current speed) was only determined to within ±5%. Additional variations of current speed at locations along the cable away from the sensor itself and small variations in experimental implementation cause the total error to be on the order of ±10%.

There was a small zero offset which was accounted for when calculating all velocities. A small nick in the signal cable, however, caused an additional, variable offset for a few days before it was detected. Of the cable data presented, only the wire rope data of July 24 is liable to be strongly affected by these offset problems. The current values calculated for that day were found by assuming a constant offset midway between the known minimum and maximum offset values. For these data points, the errors might be as much as 30% at the lower current speeds, where the relative effect of an offset will be more strongly felt. The other runs are felt to be reliable.

The tensiometer was calibrated a number of times. At the higher tensions, greater than 100 pounds, the stated values are probably good to 5%. In the low tension range, below 100 pounds, the accuracy is more on the order of 10%.

Frequency was determined by counting vibration peaks over a known time on the record, and is felt to be very accurate, within a few percent for the resonant and non-resonant sections. For the broad band, variable phase, non-lock-in periods, the accuracy is probably much lower, down to about 10%.

5.9 Test of Anti-Strumming Fairing

An experiment was performed in order to test the effectiveness of an anti-strumming fairing. The helically wound fuzz was removed from one-half of a 150-foot (46 meter) section of the braided Kevlar (see Table 1). The cable was then arranged (Figures 15,16) so that both halves could be deployed simultaneously, one directly above the other, with the same tension on each. In this way both sections were exposed to identical flow conditions. The fish was placed on the lower (unfaired) section and an accelerometer was mounted directly above it on the faired section. A sample of the results can be seen in Figure 17. The data are also tabulated in the Appendix. The test of this cable had to be curtailed due to bad weather conditions, so that only a small amount of data was collected.

The fairing had the effect of reducing the strumming frequency, but did not significantly reduce the amplitude. In applications where accelerations are more important than amplitudes, the frequency reduction alone can be valuable. The spurious pressure signals that appear on hydrophones are an example of this.

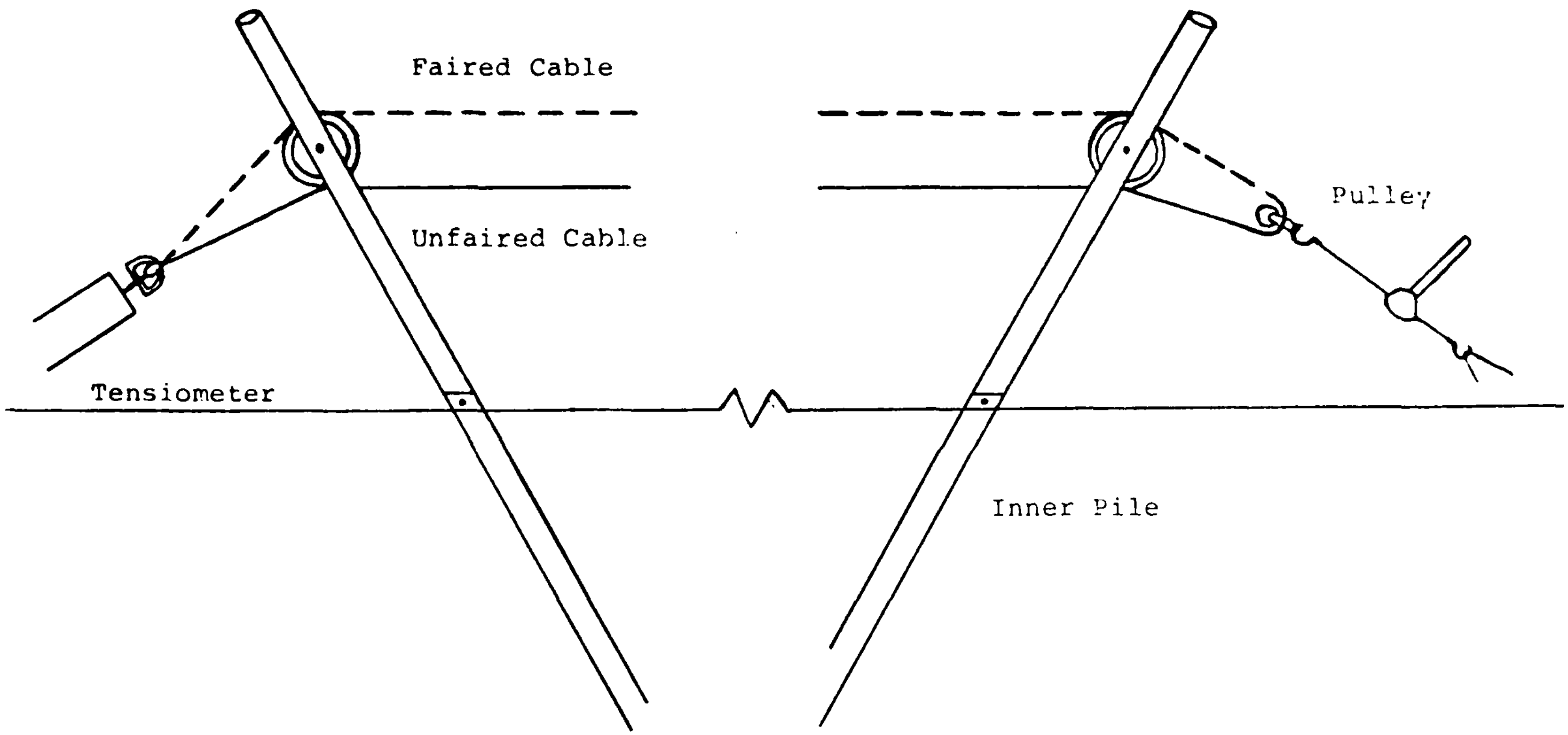


Figure 15. Cable arrangement for test of anti-strumming fairing.

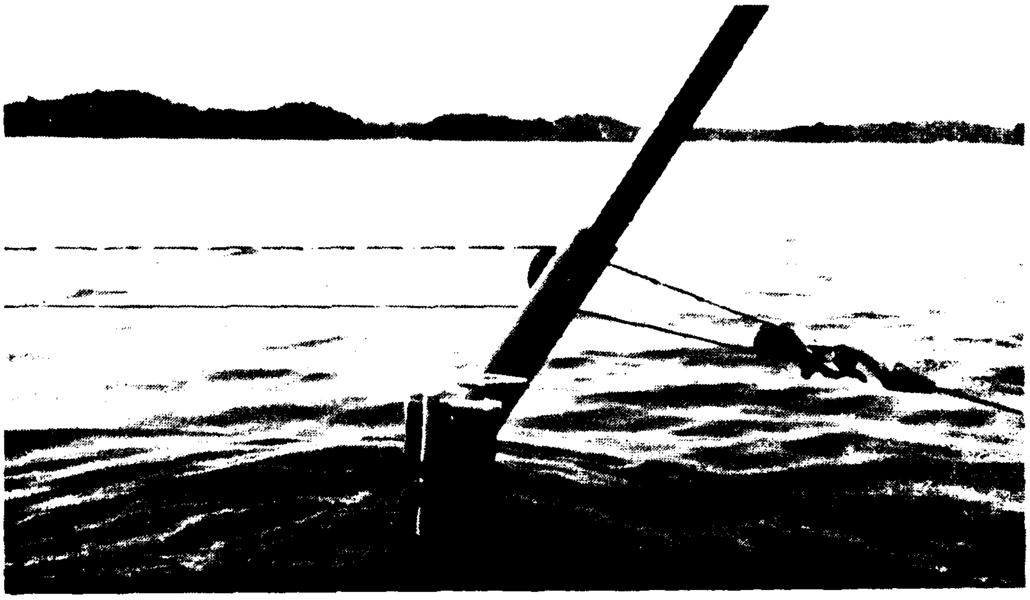


Figure 16. Photograph of tensioning arrangement for test of faired/unfaired cable. Faired section on top.

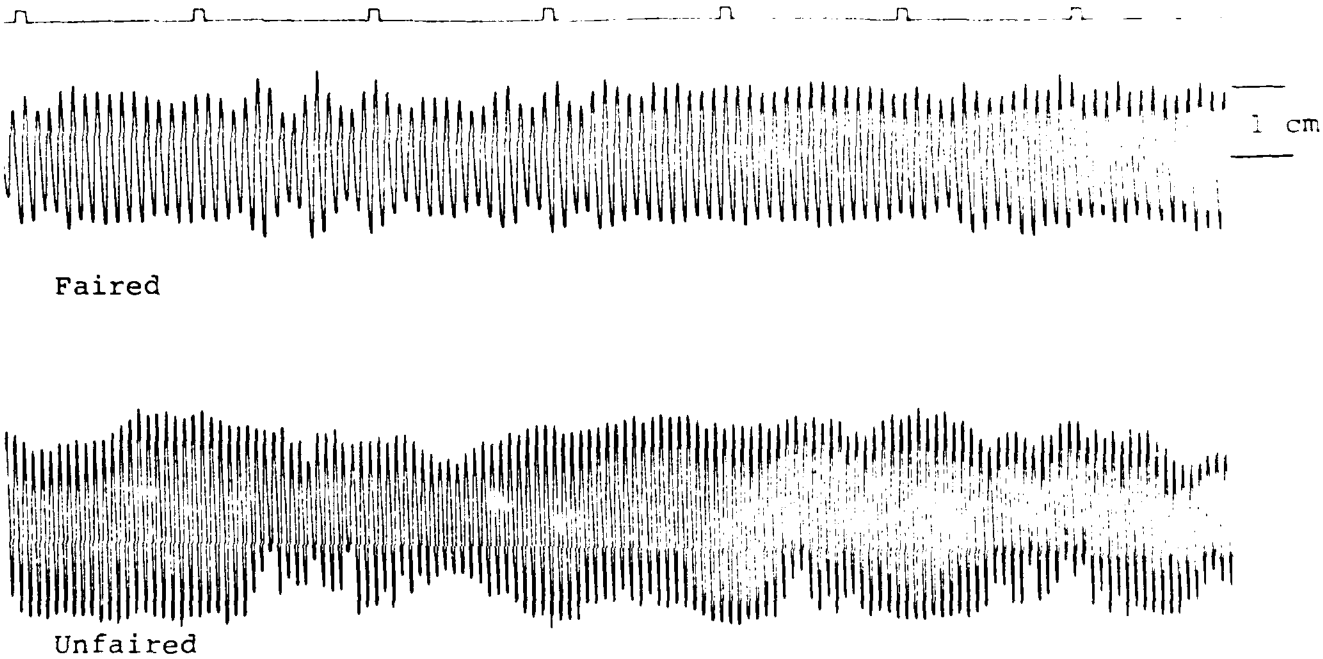


Figure 17. Test of anti-strumming fairing. Tension: 65 lbs, current: 1.5 ft/sec.
Faired section (top): 14.3 Hz, displacement .06"/cm.
Unfaired section: 18.9 Hz, displacement .076"/cm.

CHAPTER VI

DISCUSSION

The cables tested in this experiment, despite their varying physical properties, exhibited the same basic characteristics of behavior. These observed characteristics compare well with the results found for shorter cylinder lengths tested under laboratory conditions. The vibrations here termed resonant, non-resonant and non-lock-in are suggestive of a body-wake interaction with the same features as have been determined previously. This experiment has served to demonstrate the applicability of those results to the explanation, and prediction, of the response of long flexible cables in actual ocean use.

There were, however, quantitative and qualitative differences in the results for the various cables. These differences are due to the variation in structural properties of the cables. Cable damping has been found in the laboratory, and confirmed here, to be a major factor in determining the maximum amplitudes of cable vibrations (at least under resonant conditions) and the bandwidth of the lock-in region.

The wire rope had the highest mean amplitudes under all conditions. The Blue Streak followed with the next greatest amplitudes, and the Kevlar was clearly less active than either of the other two. Drawing on data from Ramberg, Griffin and Skop [29], who tested a wire rope sample, Blue Streak, and a

Kevlar rope, an estimate can be made of the log decrement for each, using 10Hz as a standard for comparison. From this the response parameter $S_G = 2\pi S^2\left(\frac{2m_v\delta}{\rho d^2}\right)$ can be calculated for each of our cables. The results are tabulated here:

CABLE	δ	m_v slugs/ft	S_G	PREDICTED $2A$
WR	.09	3.1×10^{-3}	.15	2.0
BS	.13	3.6×10^{-3}	.12	2.0
KEV	.15	4.9×10^{-3}	.13	2.0

It is not expected that these are accurate representations of the maximum amplitudes attainable under field conditions. This is merely intended to put the results in the framework of other investigators. It should also be noted that the derivation of this response parameter is based on theoretical conditions only applicable to resonant vibrations.

The differing tendencies to exhibit locked-in behavior are also attributable to the differences in damping. Wider lock-in bandwidth is associated with lower damping, and indeed in this experiment the wire rope displayed the strongest tendency to lock in over the entire vibration frequency range encountered. Only rarely did it produce wildly erratic displacement records.

The section of Blue Streak had a weaker tendency to lock in than the wire rope, but it did lock in over the entire frequency range. The Kevlar showed a much stronger lock-in behavior at low frequencies (and low mode numbers) than at the higher frequencies. These results can be seen in the data tabulations in the Appendix. The Kevlar has parallel strands which have been fixed in urethane, and as a result has a significant bending stiffness. At the higher frequencies the simple wave equation for the string is not an adequate model for the dispersive waves which occur.

The reason, or reasons, for the significant difference in the observed Strouhal numbers for the Kevlar is not yet known. Some of the distinct features of this particular cable are its large bending stiffness, the fact that is is buoyant, that it had higher damping than the other cables tested, and that it was only tensioned to a maximum of 2% of its breaking strength. As to why these should make a difference, or even if they do, remains to be determined. The Strouhal number for the other cables compares well with data found by other investigators for vibrating cylinders.

The results should be taken for what they are, which is an extension of laboratory results to a 76.5' (23.3 meter) cable deployed in the field under conditions of uniform current and tension, with little mass loading from measuring instruments. Actual uses of cables in the ocean are usually very different. The lengths utilized are much greater, approaching infinity for all practical purposes, and tensions and currents are usually not uniform. This could mean no simple natural frequencies as existed for our isolated test lengths. Behavior might be expected to always be the non-lock-in type found here. Cables are often used to support instruments in the ocean, which means lumped masses at intervals along the length. If the instruments are in cylindrical housings they, too, can shed vortices at the characteristic frequency associated with their diameter, introducing another force into the system. The cables tested here were normal, or nearly normal, to the incident flow. Very few tests have been performed on yawed cables (see [6] for example), and it remains to be determined what the effect of this might be.

This experiment also demonstrated a simple way of testing the effectiveness of anti-strumming devices by direct comparison of faired and unfaired lengths of cable under identical tension and flow conditions. It also showed the utility of the fish, a direct displacement transducer, for studies of this sort. Since its output is an exact and easily interpretable representation of the ongoing cable displacement, it is a useful tool for both on-the-spot assessments of the underwater activity and for laboratory processing of the results. Not having to adjust the output by frequency is an advantage over accelerometers in this application. If, of course, the focus of interest is the acceleration history of the cable, this does not apply.

Follow-up studies could analyse a variety of configurations, such as yawed cables, longer test lengths, higher tensions, non-uniform currents, new fairings, or lumped masses, to name a few. Improvements could be made in the design of the fish. Tests could be run to more accurately determine whether or not there are nodes in these cables, or why there are not, should that prove to be the case. It would be useful to more accurately determine actual added mass, in-water damping, and the true spacing of the natural frequencies. A preliminary extension of laboratory findings to field conditions has been established, but much more remains to be discovered.

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APPENDIX A

INSTRUMENTS

1. Accelerometers

Two single-axis, ±10g accelerometers, Entran Devices Model #EGC-240-10D, were used for amplitude and frequency measurements. They are very small units, 3.56 x 3.56 x 6.86mm, and would not mass-load the cable significantly. Their nominal sensitivity is approximately 13 mV/g, and an amplifier brought the output up to .1 V/g. Expected cable accelerations were on the order of 2-5g, producing signals of appropriate level for the tape recorder. The accelerometers were fastened to sheet metal mounts which could be easily placed on the cable, and also allowed the unit to be moved along the cable by a swimmer. A picture of an accelerometer in position can be seen in Figure 18.

Problems were encountered in the use of the accelerometers. They were oil-filled and sealed to permit immersion without a protective housing, but they were not damped. The resulting mechanical resonance of the sensing beam made the accelerometers extremely sensitive to shocks, requiring great care in a field operation. One of the accelerometers did fail completely as a result of this problem.

Changes in tension due to operation of the winch or changes in current caused the cable and attached accelerometers to rotate. Since these sensors exhibit a sine response it was

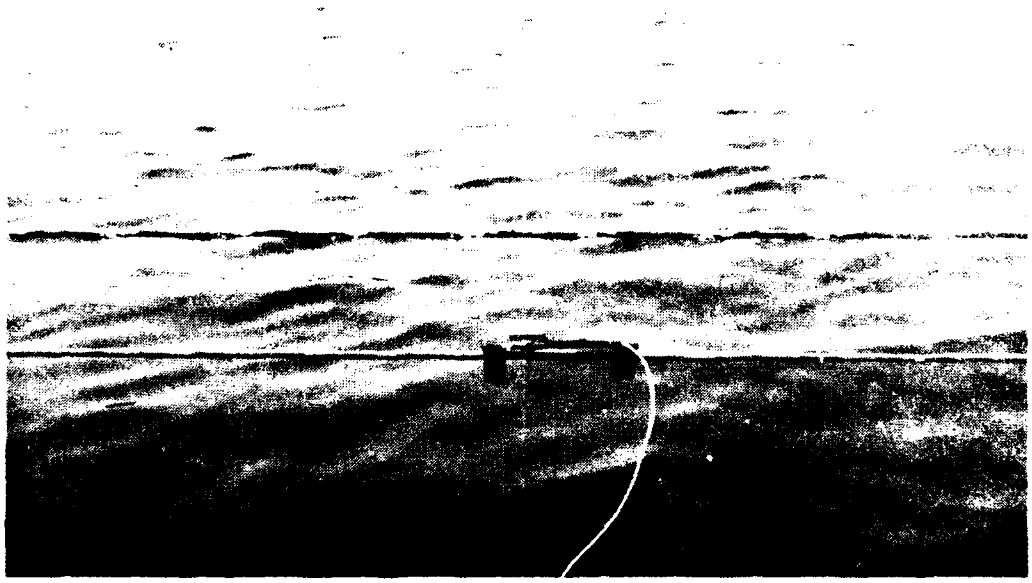


Figure 18. Photograph of accelerometer in position, on section of cable with fairing removed.

necessary to check frequently to insure that they remained within 20° of the vertical to keep errors within 5%.

The output of an acceleration-measuring device is proportional to the square of the frequency of the measured vibration. Thus high frequency motions, or components of motions, yield large output signals even when the vibration amplitudes are small. Unless a vibration is narrow-band, with weak higher harmonics, the output of an accelerometer can be difficult to interpret without resort to spectral analysis. This limits its effectiveness in a field operation, when real-time results are valuable. Confusing signals can be produced by higher-harmonic components of negligible amplitude. At very low frequencies, on the other hand, the instrument output becomes too small to process reliably, regardless of the amplitude of motion.

2. Tensiometer

A continuous record of the tension in the cable was desired. A tensiometer rated to 750 pounds was provided by the Naval Underwater Systems Center. Initial calibration was performed at the Center in the range of 50-800 pounds, and periodic checks were made in Maine by suspending known weights from the unit. The resulting plot of voltage versus tension yielded a response which was linear for tensions greater than about 75 pounds. A best-fit line yielded a relation of $T = 110V + 17.5$ in this range, with T in pounds and V in volts. This was the equation used in interpreting the tensiometer records. Comparison with the Center's calibration showed the results to be within 5-8% for tensions below 200 pounds, within 1-5% for tensions up to 350 pounds, and within 1% beyond that.

The output of the tensiometer did not seem to be entirely stable, necessitating a daily check on the zero-tension voltage, which was not zero volts. It is felt that the problem was most likely due to the circuit within the tensiometer. The instrument operates from a 30V supply. A voltage regulator within the instrument case provides a stable 24V to the pressure transducer. This transducer normally has separate outputs for power and signal ground. In order to cut down on the number of through-hull connections required, the Center installed a diode-resistor circuit which enabled a common ground to be used. This set-up is not standard, and may be the source of the inconsistencies encountered.

Attachments to the endcaps permitted rapid in-line installment with shackles. Waterproof connections were made with Mecca plugs. The cable tensions used ranged from 75 to 590 pounds, but were usually on the order of 150-250 pounds. The tensiometer output voltage was either measured with a digital voltmeter and recorded as a voice comment on the tape, or recorded directly onto a tape channel itself.

Small variations in tension accompanied the cable vibrations, and indeed could often be seen on the tension record. These fluctuating signals were very small compared to the mean tension level, however, and were not considered to be suitable for quantitative analysis.

3. Electromagnetic Current Meter

An electromagnetic current meter was furnished by Dr. John Kanwisher of Woods Hole Oceanographic Institution. The device operates on the principle that an electric charge passing through a magnetic field produces a voltage proportional to the velocity of the charge. In this case the magnetic field is supplied by a coil wound around the sensor duct, and the moving charges are the ions in the water. The resulting potential is measured by a pair of silver-silver chloride electrodes. The complete unit consists of a sensor duct, separate power and signal cables, and an on-deck control box which contains the battery power, the required electronics, and panel meter and BNC outputs.

The meter was field-calibrated by making repeated passes at constant RPM along the side of the State of Maine, the training ship of the Maine Maritime Academy. The distance was a known 500 feet (152.4 meters). The time for each pass and the average current meter reading were recorded. Reversing direction allowed the effect of water currents to be eliminated. The resulting calibration showed a linear response up to at least 5.6 feet per second (1.7 meters per second), well above any expected currents on the site. There was a zero offset of approximately 10mV. Sensitivity was 2.75 feet per second per volt (.84 meters per second per volt).

It was discovered after the third test run on July 24 that the offset voltage of the meter had apparently changed, rising to as high as 120mV. Careful checking revealed that there was a small break in the signal cable insulation, at approximately the level at which the cable entered the water when taking data on the site. Since the offset changed whenever the exposed section entered or emerged from the water, this meant that the meter readings from the previous two runs (on the first day the offset was consistent) could not be viewed with complete confidence. An offset of 120mV represents an adjustment of .33 feet per second (.10 meters per second) in current. This amounts to 15-20% at the higher currents speeds, but becomes increasingly significant as the current level drops. Since the exact offset could not be recovered, an across-the-board adjustment of 60mV, or .17 feet per second (.05 meters per second), was applied to the current data taken from those runs. Ordinarily an offset adjustment of 12mV, or .03 feet per second (.01 meters per second), was applied. No problems were encountered after the break was detected and repaired.

The sensor head was positioned approximately 1 foot behind the cable, and at a level of 2 to 3 inches above the cable, so that the vortices shed by the cable would not influence the current readings. A section of pipe was welded to a heavy metal base plate to serve as a support. A Teflon washer at the bottom of this section supported a cylinder which rode within the outer pipe, and on which was mounted a plywood board which acted as a vane. The current meter sensor unit was bolted to this board, and was thus self-orienting with the current. Observation showed that the current was essentially unidirectional throughout the tide.

4. Current-Meter Fish

The apparent success of the fish design prompted use of the basic configuration in running a current survey along the length of the cable test section. A larger, cruder model of the fish was constructed, and the EM current meter mounted in the tail, acting as the vertical fin. A section of line was tied to one arm near the point at which it met the cable. As hoped, the unit streamed out behind the cable and did not respond to the cable vibrations.

A quick traverse of the test cable was made by using the guide rope to pull the boat hand over hand across the sandbar, moving the current meter along with it. This enabled a traverse of the test section to be accomplished within 5 minutes, taking 11 measurements along the way. Rapid traversing was necessary, as the current was by no means constant in time, as mentioned previously. This test showed that the total variation at the time it was performed was no more than 5% over the length of the test section.

5. Recorders

Data were recorded on a 4-channel Tandberg Instrumentation Tape Recorder Series 100. Power was supplied in the field via a 12V automobile battery and 100 watt inverter.

At 1 7/8 inches per second, the recording speed used, the frequency response is flat from DC to 625Hz. All four channels are available for data recording, and channel 4 can also be used for voice comments. The unit is fully portable, and was housed in a waterproof wooden crate for protection.

The data signals were recorded on the .5 or 1 volt ranges. The recorder amplifies the signals to 5 volts full-scale for playback. No problems were encountered in the use of this instrument.

In addition to the instrumentation recorder, which was used for all tests, a Gould 2-channel strip-chart recorder was used for occasional hard-copy records of cable behavior. This enabled on-the-spot checks on cable behavior and instrument performance.

6. Power Supplies

The fish and accelerometers operated on 12V. This was supplied by three 6V lantern batteries powering a 12V voltage regulator chip. A precision divider circuit and voltage follower generated a "ground" level at 6V.

The tensiometer required 30V to power the 24V regulator within the unit. This was furnished by a 200ma ±15V DC power supply operated from the same inverter which powered the tape recorder.

The EM current meter ran on a battery supplied with the unit. The Gould recorder operated on Ni-Cad batteries within the unit.

APPENDIX B

COMPUTER SORTING OF CABLE DATA

Output: The heading identifies the cable and the test date for the tabulated data. Under the heading, the statement SORT BY ... lists the three parameters selected by the sorting program. The first listed is the primary choice, and is presented in the left-hand column of the output table. In case of equal values of the primary parameter, the points are sorted on the basis of the second parameter listed. Likewise, the third parameter can be used if necessary. All sorting is done in the order of highest to lowest values.

i) F: non-dimensional ratio of the observed frequency to the calculated fundamental frequency at that tension.

$$F = f/f_1 = \frac{f}{\frac{1}{2L}\sqrt{T/m_v}} = \frac{f}{\sqrt{T}}\, 2L\sqrt{m_v}$$

$2L/m_V$= constant for each cable, assuming:

a) negligible stretching (L is constant)

b) m_V = virtual mass per unit length = constant. The added mass used was simply the mass of water displaced by the cable (assumes added mass independent of frequency.

c) vibration endpoints are at the sheaves -- fixed ends

d) AC tension changes are negligible

F thus represents the relative mode of the vibration. e.g., F = 1.5 means that the observed frequency is midway between the fundamental frequency and the first harmonic at the given tension at the time of measurement.

ii) BEH: code for behavior of cable at time of measurement.

R - resonant lock-in

NR - non-resonant lock-in

N - non lock-in

Lack of a listing under this column indicates that the behavior was not specifically evaluated for this data point. This is a somewhat subjective assignment (see text for details).

iii) FREQ: observed cable vibration frequency, in cycles/second.

iv) AMP: cable vibration amplitude, zero-peak, expressed as a fraction of the cable diameter, which is listed at the top of the page. Where cable diameter changes with tension, the measured diameter under tension (75#) is used in all calculations. Where AMP is listed as 0.00, this means that the amplitude was not evaluated at this point, and not that the cable was at rest.

v) ST: represents observed Strouhal number fd/V calculated from the measured data.

vi) RE: Reynolds number, Vd/ν, using tensioned diameter, and kinematic viscosity $\nu = 1.3 \times 10^{-5}$ ft^2/sec. The seawater at ..stine was very close to 59° F, the temperature for which ..s value is listed in standard tables. The calculated

Reynolds number was rounded off to the nearest five.

vii) VEL: current speed in ft/sec, as measured by the electromagnetic current meter. The data are presented with two decimal places. Although the absolute accuracy of the measurements is only one decimal place, the second place is maintained for purposes of relative comparison of flow velocity, for which it is a valuable indication. Very small changes in current speed, on the order of .05 ft/sec, sometimes resulted in a clear shift of cable behavior from resonant to non-resonant, or vice-versa.

viii) TEN: tension in pounds. Generally these numbers are rounded off to the nearest five pounds. Where a rapid tensioning or detensioning was performed the greater accuracy was retained in order to give a more exact notion of the actual tension changes, which were often small. This information is most useful in examining the time history presentation of the data, and is of lesser importance for the other formats.

Location of fish, in feet from east end of cable:

Cable tested	Date of test	Position
Blue Streak	7/18	45.5
	7/27	45.5
Wire rope	7/24	51.5
	7/27	51.5
Kevlar	7/26	40.0
Faired/unfaired	7/28	20.0

BLUE STREAM 7/18/75 AND 7/27/75 DIAM.=.39" UNDER TENSION (7/16 NOMINAL)

TIME HISTORY

	VEL	RE	FREQ	TEN	ST	F	AMP	BEH
7/18	1.76	4450	8.9	115	0.16	7.5	0.35	N
	1.92	4865	9.3	115	0.16	7.9	0.00	
	2.14	5425	9.8	115	0.15	8.2	0.40	NR
	2.14	5425	10.0	105	0.15	8.9	0.42	N
	1.82	4615	9.1	105	0.16	8.1	0.55	R
	1.87	4740	9.5	105	0.16	8.4	0.48	NR
	1.90	4815	9.7	105	0.17	8.6	0.48	NR
	1.87	4740	9.3	195	0.16	6.0	0.47	NR
	1.84	4665	9.2	190	0.16	6.1	0.00	
	1.84	4665	9.1	195	0.16	5.9	0.00	
	1.62	4110	8.6	210	0.17	5.4	0.48	R
	1.65	4185	8.6	210	0.17	5.4	0.00	
	1.65	4185	8.7	210	0.17	5.5	0.00	
	1.57	3980	7.9	207	0.16	5.0	0.45	R
	1.51	3830	7.8	190	0.17	5.2	0.00	
	1.38	3500	7.5	176	0.18	5.1	0.48	R
	1.46	3700	7.3	165	0.16	5.2	0.00	
	1.35	3420	7.2	155	0.17	5.3	0.00	
	1.49	3775	7.2	145	0.16	5.5	0.42	NR
	1.46	3700	7.3	135	0.16	5.8	0.02	
	1.38	3500	7.2	125	0.17	5.8	0.00	
	1.43	3625	7.2	115	0.16	6.1	0.48	NR
	1.38	3500	7.0	112	0.16	6.0	0.00	
	1.32	3345	7.0	105	0.17	6.2	0.02	
	1.35	3420	6.8	101	0.16	6.1	0.00	
	1.38	3500	7.1	90	0.17	6.8	0.48	NR
	1.27	3220	6.8	81	0.17	6.9	0.00	
	1.32	3346	6.6	195	0.16	4.3	0.00	
	1.27	3222	6.6	220	0.17	4.0	0.66	R
	1.01	2560	4.8	195	0.16	3.2	0.58	R
	0.97	2460	4.8	195	0.16	3.2	0.00	
	0.35	2417	4.6	195	0.16	3.0	0.45	R

7/27

0.86	2180	4.3	195	0.16	2.8	0.30	N
0.83	2105	4.4	195	0.17	2.9	0.33	N
0.72	1825	3.3	190	0.15	2.1	0.35	N
0.62	1570	3.1	190	0.16	2.0	0.45	NR
0.60	1520	3.0	190	0.16	2.0	0.30	NR
0.47	1190	2.2	185	0.16	1.5	0.55	N
0.45	1140	2.0	185	0.14	1.3	0.51	N
1.31	4600	9.2	120	0.16	7.6	0.44	N
1.31	4600	9.2	120	0.17	7.7	0.00	
1.79	4525	9.1	120	0.17	7.6	0.00	
1.35	4050	10.7	125	0.18	8.7	0.47	N
2.06	5220	10.8	125	0.17	8.8	0.00	
1.98	5020	10.6	125	0.18	8.7	0.00	
2.03	5150	10.5	125	0.17	8.5	0.00	
1.58	5020	10.6	125	0.17	8.6	0.00	
1.46	3630	7.8	110	0.17	6.7	0.00	
1.54	3900	7.7	110	0.16	6.7	0.00	
1.51	3830	7.8	110	0.17	6.7	0.45	R
1.57	3970	7.9	110	0.16	6.8	0.00	
1.59	4040	8.2	110	0.17	7.1	0.00	
1.52	4100	8.4	110	0.17	7.2	0.47	NR
1.62	4100	7.8	190	0.16	5.2	0.41	N
1.59	4040	8.0	190	0.16	5.2	0.00	
1.57	3970	7.7	190	0.16	5.1	0.00	
1.51	3830	7.9	190	0.17	5.2	0.00	
1.54	3900	7.6	190	0.16	5.0	0.00	
1.37	3480	6.9	185	0.16	4.6	0.00	
1.40	3550	7.0	185	0.16	4.7	0.44	N
1.43	3620	7.4	185	0.17	5.0	0.00	
1.40	3550	7.4	185	0.17	4.9	0.00	
1.43	3620	7.6	185	0.17	5.0	0.42	NR
1.21	3060	5.8	175	0.16	4.0	0.00	
1.18	2990	5.8	175	0.16	4.0	0.00	N
1.18	2990	5.7	175	0.16	3.9	0.00	
1.15	2920	5.8	175	0.16	4.0	0.00	
1.10	2780	5.7	175	0.17	3.9	0.00	
1.18	2990	5.8	175	0.16	4.0	0.00	
1.13	2850	5.8	175	0.17	4.0	0.61	R
1.10	2780	5.8	175	0.17	4.0	0.00	
1.18	2990	5.7	175	0.16	3.9	0.00	

Blue Streak 7/27 cont.

0.96	2435	5.0	170	0.17	3.4	0.00	
1.04	2640	4.7	170	0.15	3.3	0.00	
0.96	2435	4.8	170	0.16	3.4	0.47	N
0.98	2225	4.6	172	0.17	3.2	0.00	
0.99	2500	4.7	170	0.16	3.3	0.00	
0.96	2435	4.5	172	0.15	3.1	0.00	
0.99	2500	4.8	170	0.16	3.3	0.00	
0.99	2500	4.6	170	0.15	3.2	0.00	
0.85	2155	4.0	170	0.15	2.8	0.40	N
0.82	2085	3.9	170	0.15	2.7	0.00	
0.30	2015	3.6	170	0.15	2.5	0.00	
0.78	1980	4.0	170	0.17	2.8	0.00	
0.81	2050	3.8	172	0.15	2.6	0.35	N
0.58	1460	3.0	170	0.17	2.1	0.00	
0.60	1530	2.8	172	0.15	2.0	0.61	R
0.55	1390	2.7	165	0.16	1.9	0.35	NR
0.55	1390	2.5	165	0.15	1.8	0.00	
0.49	1250	2.4	165	0.16	1.7	0.30	NR
0.47	1190	2.4	165	0.16	1.7	0.45	N
0.26	660	1.3	165	0.16	0.9	0.08	NR

BLUE STREAM   7/18/75 AND 7/27/75   DIAM.=.39" UNDER TENSION (7/16 NOMINAL)

SORT BY F, BEH, RE

F	BEH	FREQ	AMP	ST	RE	VEL	TEN
8.9	N	10.0	0.42	0.15	5425	2.14	125
8.7	N	10.7	0.47	0.18	4950	1.95	125
8.6	NR	9.7	0.48	0.17	4815	1.90	105
8.4	NR	9.5	0.48	0.16	4740	1.87	105
8.2	NR	9.8	0.40	0.15	5425	2.14	115
8.1	R	9.1	0.55	0.16	4615	1.82	105
7.6	N	9.2	0.44	0.16	4600	1.81	122
7.5	N	8.9	0.35	0.16	4450	1.76	115
7.2	NR	8.4	0.47	0.17	4100	1.62	112
6.8	NR	7.1	0.48	0.17	3500	1.38	92
6.7	R	7.8	0.45	0.17	3830	1.51	112
6.1	NR	7.2	0.48	0.16	3625	1.43	115
6.0	NR	9.3	0.47	0.16	4740	1.87	195
5.5	NR	7.2	0.40	0.16	3775	1.49	145
5.4	R	8.6	0.48	0.17	4110	1.62	210
5.2	N	7.8	0.41	0.16	4100	1.62	192
5.1	R	7.5	0.48	0.18	3500	1.38	176
5.0	R	7.9	0.45	0.16	3980	1.57	207
5.0	NR	7.6	0.42	0.17	3620	1.43	185
4.7	N	7.0	0.44	0.16	3550	1.40	135
4.0	R	6.6	0.66	0.17	3220	1.27	224
4.0	R	5.8	0.61	0.17	2850	1.13	175
4.0	N	5.8	0.00	0.16	2990	1.18	175
3.4	N	4.8	0.47	0.16	2435	0.96	172
3.2	R	4.8	0.58	0.16	2560	1.01	195
3.0	R	4.6	0.45	0.16	2410	0.95	195

2.9	N	4.4	0.33	0.17	2105	0.83	195
2.8	N	4.3	0.30	0.16	2180	0.86	195
2.8	N	4.0	0.40	0.15	2155	0.85	170
2.6	N	3.8	0.35	0.15	2050	0.81	170
2.1	N	3.3	0.35	0.15	1825	0.72	190
2.0	R	2.8	0.61	0.15	1530	0.60	170
2.0	NR	3.1	0.45	0.16	1570	0.62	190
2.0	NR	3.0	0.30	0.16	1520	0.60	190
1.9	NR	2.7	0.35	0.16	1390	0.55	165
1.7	NR	2.4	0.30	0.16	1250	0.49	165
1.7	N	2.4	0.45	0.16	1190	0.47	165
1.5	N	2.2	0.55	0.16	1190	0.47	185
1.3	N	2.0	0.51	0.14	1140	0.45	185
0.9	NR	1.3	0.08	0.16	660	0.26	165

BLUE STREAK 7/18/75 AND 7/27/75 DIAM.=.39" UNDER TENSION (7/16 NOMINAL)

SORT BY AMP, BEH, F

AMP	BEH	F	FREQ	ST	RE	VEL	TEN
0.66	R	4.0	6.6	0.17	3220	1.27	222
0.61	R	4.0	5.8	0.17	2850	1.13	175
0.61	R	2.2	2.8	0.15	1530	0.60	172
0.58	R	3.2	4.8	0.16	2560	1.01	195
0.55	R	8.1	9.1	0.16	4615	1.82	105
0.55	N	1.5	2.2	0.16	1190	0.47	185
0.51	N	1.3	2.0	0.14	1140	0.45	185
0.48	R	5.4	8.6	0.17	4110	1.62	212
0.48	R	5.1	7.5	0.18	3500	1.38	176
0.48	NR	8.6	9.7	0.17	4815	1.90	105
0.48	NR	8.4	9.5	0.16	4740	1.87	105
0.48	NR	6.8	7.1	0.17	3500	1.38	90
0.48	NR	6.1	7.2	0.16	3625	1.43	115
0.47	NR	7.2	8.4	0.17	4100	1.62	110
0.47	NR	6.0	9.3	0.16	4740	1.87	195
0.47	N	8.7	10.7	0.18	4950	1.95	125
0.47	N	3.4	4.8	0.16	2435	0.96	170
0.45	R	6.7	7.8	0.17	3830	1.51	117
0.45	R	5.0	7.9	0.16	3980	1.57	207
0.45	R	3.0	4.6	0.16	2410	0.95	195
0.45	NR	2.0	3.1	0.16	1570	0.62	197
0.45	N	1.7	2.4	0.16	1190	0.47	165

0.44	N	7.6	9.2	0.16	4600	1.81	120
0.44	N	4.7	7.0	0.16	3550	1.40	185
0.42	NR	5.0	7.6	0.17	3620	1.43	185
0.42	N	8.9	10.0	0.15	5425	2.14	105
0.41	N	5.2	7.8	0.16	4100	1.62	190
0.40	NR	8.2	9.8	0.15	5425	2.14	115
0.40	NR	5.5	7.2	0.16	3775	1.49	145
0.40	N	2.8	4.0	0.15	2155	0.85	170
0.35	NR	1.9	2.7	0.16	1390	0.55	165
0.35	N	7.5	8.9	0.16	4450	1.76	115
0.35	N	2.6	3.8	0.15	2050	0.81	170
0.35	N	2.1	3.3	0.15	1825	0.72	190
0.33	N	2.9	4.4	0.17	2105	0.83	195
0.30	NR	2.0	3.0	0.16	1520	0.60	190
0.30	NR	1.7	2.4	0.16	1250	0.49	165
0.30	N	2.8	4.3	0.16	2180	0.86	195
0.08	NR	0.9	1.3	0.16	660	0.26	165

BLUE STREAK 7/18/75 AND 7/27/75 DIAM.=.39" UNDER TENSION (7/16 NOMINAL)

SORT BY RE", AMP, F

BEH	F	AMP	FREQ	ST	RE	VEL	TEN
R	4.0	0.66	6.6	0.17	3220	1.27	220
R	4.0	0.61	5.8	0.17	2850	1.13	175
R	2.0	0.61	2.8	0.15	1530	0.60	170
R	3.2	0.58	4.8	0.16	2560	1.01	195
R	8.1	0.55	9.1	0.16	4615	1.82	105
R	5.4	0.48	8.6	0.17	4110	1.62	210
R	5.1	0.48	7.5	0.18	3500	1.38	176
R	6.7	0.45	7.8	0.17	3830	1.51	110
R	5.0	0.45	7.9	0.16	3980	1.57	207
R	3.0	0.45	4.6	0.16	2410	0.95	195
NR	8.6	0.48	9.7	0.17	4815	1.90	105
NR	8.4	0.48	9.5	0.16	4740	1.87	105
NR	6.8	0.48	7.1	0.17	3500	1.38	92
NR	6.1	0.48	7.2	0.16	3625	1.43	115
NR	7.2	0.47	8.4	0.17	4100	1.62	110
NR	6.0	0.47	9.3	0.16	4740	1.87	195
NR	2.2	0.45	3.1	0.16	1570	0.62	190
NR	5.0	0.42	7.6	0.17	3620	1.43	185
NR	8.2	0.40	9.8	0.15	5425	2.14	115
NR	5.6	0.40	7.2	0.16	3775	1.49	145
NR	1.9	0.35	2.7	0.16	1390	0.55	165
NR	2.0	0.30	3.0	0.16	1520	0.60	190
NR	1.7	0.30	2.4	0.16	1250	0.49	165
NR	0.9	0.08	1.3	0.16	660	0.26	165

N	1.5	0.55	2.2	0.16	1190	0.47	185
N	1.3	0.51	2.0	0.14	1140	0.45	185
N	8.7	0.47	10.7	0.18	4950	1.95	125
N	3.4	0.47	4.8	0.16	2435	0.96	170
N	1.7	0.45	2.4	0.16	1190	0.47	165
N	7.6	0.44	9.2	0.16	4600	1.81	120
N	4.7	0.44	7.0	0.16	3550	1.40	185
N	8.9	0.42	10.0	0.15	5425	2.14	105
N	5.2	0.41	7.8	0.16	4100	1.62	190
N	2.8	0.40	4.0	0.15	2155	0.85	170
N	7.5	0.35	8.9	0.16	4450	1.76	115
N	2.6	0.35	3.8	0.15	2050	0.81	170
N	2.1	0.35	3.3	0.15	1825	0.72	190
N	2.9	0.33	4.4	0.17	2105	0.83	195
N	2.8	0.30	4.3	0.16	2180	0.86	195
N	4.0	0.00	5.8	0.16	2990	1.18	175

WIRE ROPE 7/24/75 DIAM.=.275"

TIME HISTORY

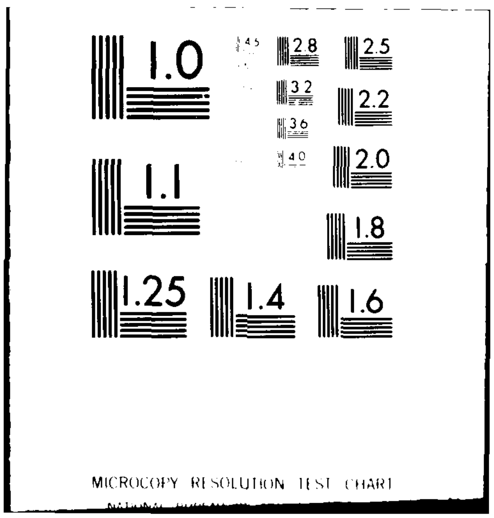
VEL	RE	FREQ	TEN	ST	F	AMP	BEH
1.40	2500	11.3	145	0.18	8.0	0.00	
1.45	2595	11.5	145	0.18	8.1	0.00	
1.62	2897	12.0	150	0.17	8.3	0.00	
1.73	3092	13.3	160	0.18	8.9	0.00	
1.98	3530	15.5	170	0.18	10.1	0.00	
1.87	3335	14.1	0	0.17	0.0	0.53	NR
1.87	3335	13.9	0	0.17	0.0	0.50	NR
1.84	3285	13.8	73	0.17	13.7	0.28	N
1.84	3285	14.4	76	0.18	14.0	0.28	N
1.84	3285	12.8	82	0.16	12.0	0.55	NR
1.81	3235	14.3	94	0.18	12.5	0.58	R
1.87	3335	14.6	106	0.18	12.0	0.39	NR
1.87	3335	14.4	130	0.18	10.7	0.00	
1.92	3430	14.2	170	0.17	9.2	0.47	NR
1.98	3530	15.4	210	0.18	9.0	0.00	
1.92	3430	15.3	257	0.18	8.1	0.30	R
1.87	3335	13.8	300	0.17	6.8	0.00	
1.89	3385	13.8	302	0.17	6.8	0.80	R
1.92	3430	14.5	345	0.17	6.6	0.69	R
1.92	3430	14.9	385	0.18	6.4	0.66	NR
2.03	3630	15.2	183	0.17	9.5	0.83	R
2.36	4220	14.7	345	0.14	6.7	0.58	NR
2.36	4220	14.6	345	0.14	6.7	0.86	R
2.53	4515	16.8	215	0.15	9.7	0.55	NR
2.53	4515	16.7	215	0.15	9.6	0.50	NR
1.92	3430	13.8	180	0.16	8.7	0.50	NR
1.81	3235	12.9	180	0.16	8.2	0.53	NR
1.81	3235	12.8	180	0.16	8.1	0.41	R
1.81	3235	12.8	180	0.16	8.1	0.00	
1.92	3430	13.0	180	0.16	8.2	0.58	NR
1.92	3430	13.8	180	0.16	8.7	0.00	

1.87	3335	12.8	182	0.16	8.1	0.58	NR
1.81	3235	12.9	185	0.16	8.1	0.53	NR
1.81	3235	13.0	180	0.16	8.2	0.19	NR
1.92	3430	12.8	180	0.15	8.0	0.44	NR
1.70	3040	14.2	182	0.19	9.0	0.44	N
1.84	3282	10.8	172	0.13	7.1	0.58	NR
1.34	2402	10.5	172	0.18	6.9	0.47	NR
1.32	2350	10.6	170	0.18	6.9	0.72	NR
1.32	2350	9.6	172	0.17	6.3	0.53	R
1.48	2645	9.8	165	0.15	6.5	0.61	NR
1.37	2450	9.6	165	0.16	6.3	0.58	NR
1.37	2450	9.6	165	0.16	6.3	0.55	R
1.04	1860	8.1	160	0.18	5.4	0.36	N
0.88	1565	6.0	160	0.16	4.0	0.41	R
0.79	1420	5.0	375	0.14	2.2	0.41	N
0.74	1320	5.3	365	0.16	2.4	0.55	NR
0.66	1170	4.6	360	0.16	2.0	0.50	R
0.66	1172	4.4	360	0.16	2.0	0.50	R
0.57	1025	4.2	362	0.17	1.9	0.64	R
0.52	925	4.1	362	0.18	1.8	0.00	
0.49	875	4.0	362	0.19	1.8	0.25	N
0.38	680	2.4	362	0.14	1.1	0.25	NR
0.35	630	2.2	360	0.14	1.0	0.22	NR

WIRE ROPE 7/24/75 DIAM.=.275"

SORT BY F, BEH, RE

F	BEH	FREQ	AMP	ST	RE	VEL	TEM
14.0	N	14.4	0.28	0.18	3285	1.84	76
13.7	N	13.8	0.28	0.17	3285	1.84	73
12.5	R	14.3	0.58	0.18	3235	1.81	94
12.0	NR	14.6	0.39	0.18	3335	1.87	106
12.0	NR	12.8	0.55	0.16	3285	1.84	82
9.7	NR	16.8	0.55	0.15	4515	2.53	215
9.6	NR	16.7	0.50	0.15	4515	2.53	210
9.5	R	15.2	0.83	0.17	3630	2.03	183
9.2	NR	14.2	0.47	0.17	3430	1.92	170
9.0	N	14.2	0.44	0.19	3240	1.70	180
8.7	NR	13.8	0.50	0.16	3430	1.92	180
8.2	NR	13.0	0.58	0.16	3430	1.92	180
8.2	NR	13.0	0.19	0.16	3235	1.81	180
8.2	NR	12.9	0.53	0.16	3235	1.81	180
8.1	R	15.3	0.30	0.18	3430	1.92	257
8.1	R	12.8	0.41	0.16	3235	1.81	180
8.1	NR	12.8	0.58	0.16	3335	1.87	180
8.1	NR	12.9	0.53	0.16	3235	1.81	185
8.0	NR	12.8	0.44	0.15	3430	1.92	180
7.1	NR	10.8	0.58	0.13	3280	1.84	170
6.9	NR	10.5	0.47	0.18	2420	1.34	170
6.9	NR	10.6	0.72	0.18	2350	1.32	170
6.8	R	13.8	0.80	0.17	3385	1.89	300
6.7	R	14.6	0.86	0.14	4220	2.36	345
6.7	NR	14.7	0.58	0.14	4220	2.36	345
6.6	R	14.5	0.69	0.17	3430	1.92	345
6.5	NR	9.8	0.61	0.15	2645	1.48	165
6.4	NR	14.9	0.66	0.18	3430	1.92	38[illegible]
[illegible]	R	9.6	0.55	0.16	2450	1.37	165
[illegible]	R	9.6	0.53	0.17	2350	1.32	170
[illegible]	NR	9.6	0.58	0.16	2450	1.37	165


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART

5.4	N	8.1	0.36	0.18	1860	1.04	160
4.0	R	6.0	0.41	0.16	1565	0.88	160
2.4	NR	5.3	0.55	0.16	1320	0.74	365
2.2	N	5.0	0.41	0.14	1420	0.79	375
2.0	R	4.6	0.50	0.16	1170	0.66	360
2.0	R	4.4	0.50	0.16	1170	0.66	360
1.9	R	4.2	0.64	0.17	1025	0.57	360
1.8	N	4.0	0.25	0.19	875	0.49	360
1.1	NR	2.4	0.25	0.14	680	0.38	360
1.0	NR	2.2	0.22	0.14	630	0.35	360
0.0	NR	13.9	0.50	0.17	3335	1.87	0
0.0	NR	14.1	0.53	0.17	3335	1.87	0

WIRE ROPE 7/24/75 DIAM.=.275"

SORT BY AMP, BEH, F

AMP	BEH	F	FREQ	ST	RE	VEL	TEN
0.86	R	6.7	14.6	0.14	4220	2.36	345
0.83	R	9.5	15.2	0.17	3630	2.03	133
0.80	R	6.8	13.8	0.17	3385	1.89	300
0.72	NR	6.9	10.6	0.18	2350	1.32	170
0.69	R	6.6	14.5	0.17	3430	1.92	345
0.66	NR	6.4	14.9	0.18	3430	1.92	385
0.64	R	1.9	4.2	0.17	1025	0.57	360
0.61	NR	6.5	9.8	0.15	2645	1.48	165
0.58	R	12.5	14.3	0.18	3235	1.81	94
0.58	NR	8.2	13.0	0.16	3430	1.92	180
0.58	NR	8.1	12.8	0.16	3335	1.87	180
0.58	NR	7.1	10.8	0.13	3280	1.84	170
0.58	NR	6.7	14.7	0.14	4220	2.36	345
0.58	NR	6.3	9.6	0.16	2450	1.37	165
0.55	R	6.3	9.6	0.16	2450	1.37	165
0.55	NR	12.0	12.8	0.16	3285	1.84	82
0.55	NR	9.7	16.8	0.15	4515	2.53	215
0.55	NR	2.4	5.3	0.16	1320	0.74	365
0.53	R	6.3	9.6	0.17	2350	1.32	170
0.53	NR	8.2	12.9	0.16	3235	1.81	180
0.53	NR	8.1	12.9	0.16	3235	1.81	185
0.53	NR	0.0	14.1	0.17	3335	1.87	0
0.50	R	2.0	4.6	0.16	1170	0.66	360
0.50	R	2.0	4.4	0.16	1170	0.66	360
0.50	NR	9.6	16.7	0.15	4515	2.53	215
0.50	NR	8.7	13.8	0.16	3430	1.92	180
0.50	NR	0.0	13.9	0.17	3335	1.87	0

0.47	NR	9.2	14.2	0.17	3430	1.92	170
0.47	NR	6.9	10.5	0.18	2400	1.34	170
0.44	NR	8.0	12.8	0.15	3430	1.92	180
0.44	N	9.0	14.2	0.19	3040	1.70	180
0.41	R	8.1	12.8	0.16	3235	1.81	180
0.41	R	4.0	6.0	0.16	1565	0.88	160
0.41	N	2.2	5.0	0.14	1420	0.79	375
0.39	NR	12.0	14.6	0.18	3335	1.87	106
0.36	N	5.4	8.1	0.18	1860	1.04	160
0.30	R	8.1	15.3	0.18	3430	1.92	257
0.28	N	14.0	14.4	0.18	3285	1.84	76
0.28	N	13.7	13.8	0.17	3285	1.84	73
0.25	NR	1.1	2.4	0.14	680	0.38	360
0.25	N	1.8	4.0	0.19	875	0.49	360
0.22	NR	1.0	2.2	0.14	630	0.35	360
0.19	NR	8.2	13.0	0.16	3235	1.81	180

WIRE ROPE 7/24/75 DIAM.=.275"

SORT BY REG, AMP, F

BEH	F	AMP	FREQ	ST	RE	VEL	TEN
R	6.7	0.86	14.6	0.14	4220	2.36	345
R	9.5	0.83	15.2	0.17	3630	2.03	183
R	6.8	0.80	13.8	0.17	3385	1.89	300
R	6.6	0.69	14.5	0.17	3430	1.92	345
R	1.9	0.64	4.2	0.17	1025	0.57	360
R	12.5	0.58	14.3	0.18	3235	1.81	94
R	6.3	0.55	9.6	0.16	2450	1.37	165
R	6.3	0.53	9.6	0.17	2350	1.32	170
R	2.0	0.50	4.6	0.16	1170	0.66	360
R	2.0	0.50	4.4	0.16	1170	0.66	360
R	8.1	0.41	12.8	0.16	3235	1.81	180
R	4.0	0.41	6.0	0.16	1565	0.88	160
R	8.1	0.30	15.3	0.18	3430	1.92	257
NR	6.9	0.72	10.6	0.18	2350	1.32	170
NR	6.4	0.66	14.9	0.18	3430	1.92	385
NR	6.5	0.61	9.8	0.15	2645	1.48	165
NR	8.2	0.58	13.0	0.16	3430	1.92	180
NR	8.1	0.58	12.8	0.16	3335	1.87	184
NR	7.1	0.58	10.8	0.13	3280	1.84	170
NR	6.7	0.58	14.7	0.14	4220	2.36	345
NR	6.3	0.58	9.6	0.16	2450	1.37	165
NR	12.0	0.55	12.8	0.16	3285	1.84	82
NR	9.7	0.55	16.8	0.15	4515	2.53	215
NR	2.4	0.55	5.3	0.16	1320	0.74	365
NR	8.2	0.53	12.9	0.16	3235	1.81	180
NR	8.1	0.53	12.9	0.16	3235	1.81	185
NR	0.0	0.53	14.1	0.17	3335	1.87	2
NR	9.6	0.50	16.7	0.15	4515	2.53	215

NR	8.7	0.50	13.8	0.16	3430	1.92	180
NR	0.0	0.50	13.9	0.17	3335	1.87	0
NR	9.2	0.47	14.2	0.17	3430	1.92	170
NR	6.9	0.47	10.5	0.18	2400	1.34	170
NR	8.0	0.44	12.8	0.15	3430	1.92	180
NR	12.0	0.39	14.6	0.18	3335	1.87	106
NR	1.1	0.25	2.4	0.14	680	0.38	360
NR	1.0	0.22	2.2	0.14	630	0.35	360
NR	8.2	0.19	13.0	0.16	3235	1.81	180
N	9.0	0.44	14.2	0.19	3040	1.70	180
N	2.2	0.41	5.0	0.14	1420	0.79	375
N	5.4	0.36	8.1	0.18	1860	1.04	160
N	14.0	0.28	14.4	0.18	3285	1.84	76
N	13.7	0.28	13.8	0.17	3285	1.84	73
N	1.8	0.25	4.0	0.19	875	0.49	360

WIRE ROPE 7/27/75 DIAM.=.275"

TIME HISTORY

VEL	RE	FREQ	TEN	ST	F	AMP	BEH
2.17	3880	14.2	105	0.15	11.8	0.61	NR
2.17	3880	15.8	123	0.17	12.1	0.50	NR
2.28	4075	16.5	143	0.17	11.7	1.02	R
2.28	4075	15.8	147	0.16	11.1	0.61	NR
2.34	4185	16.9	172	0.17	11.0	0.44	N
2.23	3985	18.2	202	0.19	10.8	0.28	N
2.34	4185	17.4	255	0.17	9.3	0.55	NR
2.39	4270	18.2	310	0.18	8.8	0.50	NR
2.34	4185	16.6	362	0.16	7.4	0.55	NR
2.23	3985	17.5	415	0.18	7.3	0.44	N
2.23	3985	17.8	435	0.18	7.2	0.39	N
2.17	3880	16.0	435	0.17	6.5	0.58	NR
2.12	3790	16.7	490	0.18	6.4	0.58	NR
2.12	3790	16.4	480	0.18	6.4	0.39	NR
2.12	3790	15.6	535	0.17	5.7	0.58	NR
2.06	3680	15.4	525	0.17	5.7	0.58	NR
2.01	3595	15.3	525	0.18	5.7	0.58	NR
2.01	3595	14.2	590	0.16	5.0	0.55	NR
2.01	3595	14.5	590	0.16	5.0	0.50	NR
2.01	3595	14.5	580	0.16	5.1	0.50	NR
2.17	3880	14.4	570	0.15	5.1	0.50	NR
2.17	3880	15.9	555	0.17	5.7	0.55	NR
2.17	3880	14.9	460	0.16	5.9	0.61	NR
2.17	3880	13.7	375	0.14	6.0	0.72	NR
2.17	3880	15.8	300	0.17	7.8	0.33	R
2.17	3880	14.8	250	0.16	8.0	0.53	NR
2.17	3880	16.2	210	0.17	9.5	0.77	NR
2.34	4180	17.5	170	0.17	11.4	0.94	R
2.34	4180	16.6	155	0.16	11.3	0.83	NR
2.23	3085	15.9	145	0.16	11.2	0.33	NR
2.23	3085	15.6	135	0.16	11.4	0.00	
2.28	4075	15.0	120	0.15	11.6	0.00	

WIRE ROPE 7/27/75 DIAM.=.275"

SORT BY F, BEH, RE

F	BEH	FREQ	AMP	ST	RE	VEL	TEN
12.1	NR	15.8	0.50	0.17	3880	2.17	123
11.8	NR	14.2	0.61	0.15	3880	2.17	105
11.7	R	16.5	1.72	0.17	4075	2.28	143
11.4	R	17.5	0.94	0.17	4180	2.34	17[illegible]
11.3	NR	16.6	0.83	0.16	4180	2.34	155
11.2	NR	15.9	0.33	0.16	3985	2.23	145
11.1	NR	15.8	0.61	0.16	4075	2.28	147
11.0	N	16.9	0.44	0.17	4185	2.34	172
10.8	N	18.2	0.28	0.19	3985	2.23	202
9.5	NR	16.2	0.77	0.17	3880	2.17	21[illegible]
9.3	NR	17.4	0.55	0.17	4185	2.34	255
8.8	NR	18.2	0.50	0.18	4270	2.39	312
8.0	NR	14.8	0.53	0.16	3880	2.17	25[illegible]
7.8	R	15.8	0.33	0.17	3880	2.17	30[illegible]
7.4	NR	16.6	0.55	0.16	4185	2.34	36[illegible]
7.3	N	17.5	0.44	0.18	3985	2.23	415
7.2	N	17.8	0.39	0.18	3985	2.23	435
6.5	NR	16.0	0.58	0.17	3880	2.17	435
6.4	NR	16.7	0.58	0.18	3790	2.12	49[illegible]
6.4	NR	16.4	0.39	0.18	3790	2.12	48[illegible]
6.0	NR	13.7	0.72	0.14	3880	2.17	375
5.9	NR	14.9	0.61	0.16	3880	2.17	462
5.7	NR	15.9	0.55	0.17	3880	2.17	555
5.7	NR	15.6	0.58	0.17	3790	2.12	535
5.7	NR	15.4	0.58	0.17	3680	2.06	525
5.7	NR	15.3	0.58	0.18	3595	2.01	525
5.1	NR	14.4	0.50	0.15	3880	2.17	57[illegible]
5.1	NR	14.5	0.50	0.16	3595	2.01	58[illegible]
5.0	NR	14.5	0.50	0.16	3595	2.01	59[illegible]
5.0	NR	14.2	0.55	0.14	3595	2.01	59[illegible]

WIRE ROPE 7/27/75 DIAM.=.275"

SORT BY AMP, BEH, F

AMP	BEH	F	FREQ	ST	RE	VEL	TEN
1.02	R	11.7	16.5	0.17	4075	2.28	143
0.94	R	11.4	17.5	0.17	4180	2.34	170
0.83	NR	11.3	16.6	0.16	4180	2.34	155
0.77	NR	9.5	16.2	0.17	3880	2.17	210
0.72	NR	6.0	13.7	0.14	3880	2.17	375
0.61	NR	11.8	14.2	0.15	3880	2.17	105
0.61	NR	11.1	15.8	0.16	4075	2.28	147
0.61	NR	5.9	14.9	0.16	3880	2.17	460
0.58	NR	6.5	16.0	0.17	3880	2.17	435
0.58	NR	6.4	16.7	0.18	3790	2.12	490
0.58	NR	5.7	15.6	0.17	3790	2.12	535
0.58	NR	5.7	15.4	0.17	3680	2.06	525
0.58	NR	5.7	15.3	0.18	3595	2.01	525
0.55	NR	9.3	17.4	0.17	4185	2.34	255
0.55	NR	7.4	16.6	0.16	4185	2.34	360
0.55	NR	5.7	15.9	0.17	3880	2.17	555
0.55	NR	5.0	14.2	0.16	3595	2.01	590
0.53	NR	8.0	14.8	0.16	3880	2.17	250
0.50	NR	12.1	15.8	0.17	3880	2.17	123
0.50	NR	8.8	18.2	0.18	4270	2.39	310
0.50	NR	5.1	14.5	0.16	3595	2.01	580
0.50	NR	5.1	14.4	0.15	3880	2.17	577
0.50	NR	5.0	14.5	0.16	3595	2.01	590
0.44	N	11.0	16.9	0.17	4185	2.34	172
0.44	N	7.3	17.5	0.18	3985	2.23	415
0.39	NR	6.4	16.4	0.18	3790	2.12	480
0.39	N	7.2	17.8	0.18	3985	2.23	435
0.33	R	7.8	15.8	0.17	3880	2.17	300
0.33	NR	11.2	15.9	0.16	3985	2.23	145
0.28	N	10.8	18.2	0.19	3985	2.23	202

WIRE ROPE 7/27/75 DIAM.=.275"

SORT BY BEH, AMP, F

BEH	F	AMP	FREQ	ST	RE	VEL	TEN
R	11.7	1.02	16.5	0.17	4075	2.28	143
R	11.4	0.94	17.5	0.17	4180	2.34	170
R	7.8	0.33	15.8	0.17	3880	2.17	300
NR	11.3	0.83	16.6	0.16	4180	2.34	155
NR	9.5	0.77	16.2	0.17	3880	2.17	214
NR	6.0	0.72	13.7	0.14	3880	2.17	375
NR	11.8	0.61	14.2	0.15	3882	2.17	105
NR	11.1	0.61	15.8	0.16	4075	2.28	147
NR	5.9	0.61	14.9	0.16	3880	2.17	460
NR	6.5	0.58	16.0	0.17	3882	2.17	435
NR	6.4	0.58	16.7	0.18	3790	2.12	490
NR	5.7	0.58	15.4	0.17	3680	2.06	525
NR	5.7	0.58	15.3	0.18	3595	2.01	525
NR	5.7	0.58	15.6	0.17	3790	2.12	535
NR	9.3	0.55	17.4	0.17	4185	2.34	255
NR	7.4	0.55	16.6	0.16	4185	2.34	360
NR	5.7	0.55	15.9	0.17	3880	2.17	555
NR	5.7	0.55	14.2	0.16	3595	2.01	590
NR	8.[illegible]	0.53	14.8	0.16	3880	2.17	250
NR	12.1	0.50	15.8	0.17	3880	2.17	123
NR	8.8	0.50	18.2	0.18	4270	2.39	310
NR	5.1	0.50	14.4	0.15	3880	2.17	570
NR	5.1	0.50	14.5	0.16	3595	2.01	580
NR	5.0	0.50	14.5	0.16	3595	2.01	592
NR	6.4	0.39	16.4	0.18	3790	2.12	483
NR	11.2	0.33	15.9	0.16	3985	2.23	145
N	11.0	0.44	16.9	0.17	4185	2.34	172
N	7.3	0.44	17.5	0.18	3985	2.23	415
N	7.2	0.39	17.8	0.18	3985	2.23	435
N	10.8	0.28	18.2	0.19	3985	2.23	202

KEVLAR 5/26/75 DIAM.=.485"

TIME HISTORY

VEL	RE	FREQ	TEN	ST	F	AMP	BEH
2.17	6840	12.0	112	0.22	12.2	0.00	
2.17	6840	11.5	119	0.21	11.3	0.18	N
2.17	6840	11.7	122	0.22	11.4	0.30	N
2.17	6840	11.5	129	0.21	10.9	0.34	N
2.17	6840	11.5	144	0.21	10.3	0.31	N
2.17	6840	12.0	156	0.22	10.3	0.00	
2.17	6840	11.6	177	0.22	9.4	0.00	
2.17	6840	12.1	201	0.22	9.2	0.28	N
2.17	6840	11.2	221	0.21	8.1	0.00	
2.17	6840	11.4	244	0.21	7.8	0.00	
2.17	6840	11.2	273	0.21	7.3	0.24	N
2.06	6500	10.4	295	0.20	6.5	0.00	
2.06	6500	10.5	325	0.21	6.3	0.13	N
1.84	5800	10.1	345	0.22	5.8	0.00	
1.84	5800	9.0	360	0.20	5.1	0.00	
1.84	5800	9.4	360	0.21	5.3	0.13	N
1.51	4760	7.9	422	0.21	4.1	0.00	
2.01	6340	10.0	285	0.20	6.4	0.24	N
2.06	6500	11.1	285	0.22	7.1	0.00	
2.06	6500	11.6	285	0.23	7.4	0.00	
2.06	6500	11.0	285	0.22	7.0	0.00	
2.12	6670	11.8	285	0.23	7.5	0.31	N
1.29	4070	7.4	245	0.23	5.1	0.34	NR
1.29	4070	7.3	245	0.23	5.0	0.00	
1.29	4070	7.3	245	0.23	5.0	0.00	
1.29	4070	7.2	245	0.22	5.0	0.00	
1.32	4155	7.2	245	0.22	5.0	0.47	R
1.35	4240	7.5	250	0.22	5.1	0.00	
1.40	4415	7.9	250	0.23	5.4	0.34	N
1.37	4330	7.8	250	0.23	5.3	0.31	R

1.32	4155	7.6	250	0.23	5.2	0.00	
1.07	3375	6.0	240	0.23	4.2	0.20	R
1.07	3375	5.8	240	0.22	4.1	0.24	R
1.04	3290	5.8	240	0.22	4.0	0.00	
1.02	3200	5.6	240	0.22	3.9	0.28	R
1.00	3160	5.7	240	0.23	4.0	0.00	
1.03	3240	5.8	240	0.23	4.0	0.17	R
1.02	3200	5.8	240	0.23	4.0	0.00	
1.32	4155	7.3	240	0.22	5.1	0.40	R
1.35	4240	7.4	245	0.22	5.1	0.00	
1.40	4415	7.6	245	0.22	5.2	0.33	NR
1.46	4590	8.6	245	0.24	5.9	0.00	
1.40	4415	7.9	245	0.23	5.4	0.00	
1.40	4415	8.6	245	0.25	5.9	0.25	NR
1.43	4500	7.5	245	0.21	5.2	0.33	NR
1.43	4500	8.8	245	0.25	6.0	0.31	NR
1.57	4935	9.0	255	0.23	6.1	0.28	R
1.54	4850	9.2	255	0.24	6.2	0.28	NR
1.04	3290	6.6	230	0.26	4.7	0.00	
0.99	3115	5.6	230	0.23	4.0	0.31	R
0.93	2940	5.4	225	0.23	3.8	0.00	
0.93	2940	5.3	225	0.23	3.8	0.27	NR
0.91	2850	5.3	225	0.24	3.8	0.00	
0.89	2810	5.2	225	0.23	3.7	0.25	NR
0.84	2640	4.6	225	0.22	3.3	0.40	R
0.85	2680	4.6	225	0.22	3.3	0.00	
0.82	2590	4.5	225	0.22	3.2	0.00	
0.75	2375	4.4	225	0.23	3.1	0.40	R
0.75	2375	4.1	225	0.22	2.9	0.35	NR
0.74	2330	3.8	225	0.21	2.8	0.30	NR
0.71	2245	3.9	225	0.22	2.8	0.34	R
0.62	1940	3.6	220	0.23	2.6	0.40	R
0.63	1990	3.6	220	0.23	2.6	0.00	
0.37	1160	1.6	220	0.17	1.2	0.27	NR
0.26	815	1.5	220	0.23	1.1	0.23	N
0.52	1640	2.9	220	0.23	2.1	0.00	
0.58	1815	3.1	220	0.22	2.2	0.20	R
0.33	1030	1.5	220	0.18	1.1	0.00	R
0.28	880	1.5	220	0.22	1.1	0.00	

KEVLAR 7/26/75 DIAM.=.485"

SORT BY F, BFH, RE

F	BFH	FREQ	AMP	ST	RE	VEL	TEN
11.4	N	11.7	0.30	0.22	6840	2.17	122
11.3	N	11.5	0.18	0.21	6840	2.17	119
10.9	N	11.5	0.34	0.21	6840	2.17	129
10.3	N	11.5	0.31	0.21	6840	2.17	144
9.2	N	12.1	0.28	0.22	6840	2.17	201
7.5	N	11.8	0.31	0.23	6670	2.12	285
7.3	N	11.2	0.24	0.21	6840	2.17	273
6.4	N	10.0	0.24	0.20	6340	2.01	285
6.3	N	10.5	0.13	0.21	6500	2.06	325
6.2	NR	9.2	0.28	0.24	4850	1.54	255
6.1	R	9.0	0.28	0.23	4935	1.57	255
6.0	NR	8.8	0.31	0.25	4500	1.43	245
5.9	NR	8.6	0.25	0.25	4415	1.40	245
5.4	N	7.9	0.34	0.23	4415	1.40	257
5.3	R	7.8	0.31	0.23	4330	1.37	254
5.3	N	9.4	0.13	0.21	5800	1.84	36[illegible]
5.2	NR	7.5	0.33	0.21	4500	1.43	245
5.2	NR	7.6	0.33	0.22	4415	1.40	245
5.1	R	7.3	0.40	0.22	4155	1.32	247
5.1	NR	7.4	0.34	0.23	4070	1.29	245
5.0	R	7.2	0.47	0.22	4155	1.32	245

4.2	R	6.0	0.20	0.23	3375	1.07	240
4.1	R	5.8	0.24	0.22	3375	1.07	240
4.0	R	5.8	0.17	0.23	3240	1.03	240
4.0	R	5.6	0.31	0.23	3115	0.99	232
3.9	R	5.6	0.28	0.22	3200	1.02	240
3.8	NR	5.3	0.27	0.23	2940	0.93	225
3.7	NR	5.2	0.25	0.23	2810	0.89	225
3.3	R	4.6	0.40	0.22	2640	0.84	225
3.1	R	4.4	0.40	0.23	2375	0.75	225
2.9	NR	4.1	0.35	0.22	2375	0.75	225
2.8	R	3.9	0.34	0.22	2245	0.71	225
2.8	NR	3.8	0.30	0.21	2330	0.74	225
2.6	R	3.6	0.40	0.23	1940	0.62	220
2.2	R	3.1	0.00	0.22	1815	0.58	220
1.2	NR	1.6	0.27	0.17	1160	0.37	220
1.1	R	1.5	0.00	0.18	1030	0.33	220
1.1	N	1.5	0.23	0.23	815	0.26	220

KEVLAR 7/26/75 DIAM.=.485"

SORT BY AMP, BEH, F

AMP	BEH	F	FREQ	ST	RE	VEL	TEN
0.47	R	5.0	7.2	0.22	4155	1.32	245
0.40	R	5.1	7.3	0.22	4155	1.32	242
0.40	R	3.3	4.6	0.22	2640	0.84	225
0.40	R	3.1	4.4	0.23	2375	0.75	225
0.40	R	2.6	3.6	0.23	1940	0.62	220
0.35	NR	2.9	4.1	0.22	2375	0.75	225
0.34	R	2.8	3.9	0.22	2245	0.71	225
0.34	NR	5.1	7.4	0.23	4070	1.29	245
0.34	N	10.9	11.5	0.21	6840	2.17	129
0.34	N	5.4	7.9	0.23	4415	1.40	250
0.33	NR	5.2	7.5	0.21	4500	1.43	245
0.33	NR	5.2	7.6	0.22	4415	1.40	245
0.31	R	5.3	7.8	0.23	4330	1.37	250
0.31	R	4.0	5.6	0.23	3115	0.99	230
0.31	NR	6.0	8.8	0.25	4500	1.43	245
0.31	N	10.3	11.5	0.21	6840	2.17	144
0.31	N	7.5	11.8	0.23	6670	2.12	235
0.30	NR	2.8	3.8	0.21	2330	0.74	225
0.30	N	11.4	11.7	0.22	6840	2.17	122
0.28	R	6.1	9.0	0.23	4935	1.57	255
0.28	R	3.9	5.6	0.22	3200	1.02	240
0.28	NR	6.2	9.2	0.24	4850	1.54	255
0.28	N	9.2	12.1	0.22	6840	2.17	201
0.27	NR	3.8	5.3	0.23	2940	0.93	225
0.27	NR	1.2	1.6	0.17	1160	0.37	220
0.25	NR	5.9	8.6	0.25	4415	1.40	245
0.25	NR	3.7	5.2	0.23	2810	0.89	225

0.24	R	4.1	5.8	0.22	3375	1.07	240
0.24	N	7.3	11.2	0.21	6840	2.17	273
0.24	N	6.4	10.0	0.20	6340	2.01	285
0.23	N	1.1	1.5	0.23	815	0.26	220
0.20	R	4.2	6.0	0.23	3375	1.07	240
0.18	N	11.3	11.5	0.21	6840	2.17	119
0.17	R	4.0	5.8	0.23	3240	1.03	240
0.13	N	6.3	10.5	0.21	6500	2.06	325
0.13	N	5.3	9.4	0.21	5800	1.84	360

KEVLAR 7/24/75 DIAM.=.485"

SORT BY BEH, AMP, F

BEH	F	AMP	FREQ	ST	RE	VEL	TEN
R	5.0	0.47	7.2	0.22	4155	1.32	245
R	5.1	0.40	7.3	0.22	4155	1.32	240
R	3.3	0.40	4.6	0.22	2640	0.54	225
R	3.1	0.40	4.4	0.23	2375	0.75	225
R	2.6	0.40	3.6	0.23	1940	0.62	220
R	2.8	0.34	3.9	0.22	2245	0.71	225
R	5.3	0.31	7.8	0.23	4330	1.37	250
R	4.0	0.31	5.6	0.23	3115	0.99	230
R	6.1	0.28	9.0	0.23	4935	1.57	255
R	3.9	0.28	5.6	0.22	3200	1.22	240
R	4.1	0.24	5.8	0.22	3375	1.07	240
R	4.2	0.20	6.0	0.23	3375	1.07	240
R	4.0	0.17	5.8	0.23	3240	1.03	240
R	2.2	0.00	3.1	0.22	1815	0.58	220
R	1.1	0.00	1.5	0.18	1030	0.33	225
NR	2.9	0.35	4.1	0.22	2375	0.75	225
NR	5.1	0.34	7.4	0.23	4070	1.29	245
NR	5.2	0.33	7.6	0.22	4415	1.40	245
NR	5.2	0.33	7.5	0.21	4500	1.43	245
NR	6.0	0.31	8.8	0.25	4500	1.43	245
NR	2.8	0.30	3.8	0.21	2330	0.74	225
NR	6.2	0.28	9.2	0.24	4850	1.54	255
NR	3.9	0.27	5.3	0.23	2940	0.93	225
NR	1.2	0.27	1.6	0.17	1160	0.37	225
NR	5.9	0.25	8.6	0.25	4415	1.40	245
NR	3.7	0.25	5.2	0.23	2810	0.89	225

N	10.9	0.34	11.5	0.21	6840	2.17	129
N	5.4	0.34	7.9	0.23	4415	1.40	250
N	10.3	0.31	11.5	0.21	6840	2.17	144
N	7.5	0.31	11.8	0.23	6670	2.12	285
N	11.4	0.30	11.7	0.22	6840	2.17	122
N	9.2	0.28	12.1	0.22	6840	2.17	201
N	7.3	0.24	11.2	0.21	6840	2.17	273
N	6.4	0.24	10.0	0.20	6340	2.01	285
N	1.1	0.23	1.5	0.23	815	0.26	220
N	11.3	0.18	11.5	0.21	6840	2.17	119
N	6.3	0.13	10.5	0.21	6500	2.06	325
N	5.3	0.13	9.4	0.21	5800	1.84	360

UNJACKETED KEVLAR WITH AND WITHOUT FAIRING 7/28/75 DIAM.=.154"

TIME HISTORY

VEL	RE	FREQ	TEN	ST	F	AMP	BEH
2.01	2000	26.8	70	0.17	11.6	0.40	N
1.98	1980	26.1	70	0.17	0.0	0.00	
2.01	2000	25.6	70	0.16	11.1	0.40	NR
1.98	1980	26.0	70	0.17	0.0	0.00	
2.01	2000	27.8	70	0.18	12.1	0.34	N
1.95	1950	27.2	70	0.18	11.2	0.45	R
1.90	1900	24.5	70	0.17	0.0	0.00	
1.90	1900	24.8	70	0.17	10.8	0.40	N
● 1.90	1900	17.9	70	0.12	0.0	0.38	NR
1.90	1900	24.5	70	0.17	10.6	0.49	NR
● 1.90	1900	17.8	70	0.12	8.0	0.41	NR
1.87	1870	25.2	65	0.17	0.0	0.00	
● 1.87	1870	17.9	65	0.12	0.0	0.00	
1.48	1485	18.9	65	0.16	8.5	0.62	R
● 1.48	1485	14.3	65	0.12	6.4	0.34	NR
1.51	1510	19.8	65	0.17	0.0	0.00	
● 1.51	1510	14.8	65	0.13	0.0	0.00	
1.54	1540	19.9	65	0.17	9.0	0.64	NR
● 1.54	1540	14.6	65	0.12	6.5	0.34	NR
1.59	1595	21.8	65	0.18	0.0	0.00	
● 1.59	1595	15.1	65	0.12	0.0	0.00	
2.14	2145	29.3	65	0.18	13.2	0.40	NR
● 2.14	2145	21.0	65	0.13	9.3	0.38	N
2.12	2115	28.8	65	0.17	0.0	0.00	
● 2.12	2115	21.2	65	0.13	0.0	0.00	

● -- faired cable

UNJACKETED KEVLAR WITH AND WITHOUT FAIRING   7/28/75   DIAM.=.154"

SORT BY F, BEH, RE

F	BEH	FREQ	AMP	ST	RE	VEL	TEN
13.2	NR	29.3	0.40	0.18	2145	2.14	65
12.1	N	27.8	0.34	0.18	2000	2.01	72
11.6	N	26.8	0.40	0.17	2000	2.01	72
11.2	R	27.2	0.45	0.18	1950	1.95	7[illegible]
11.1	NR	25.6	0.40	0.16	2000	2.01	72
10.8	N	24.8	0.40	0.17	1900	1.90	72
10.6	NR	24.5	0.49	0.17	1900	1.90	7[illegible]
● 9.3	N	21.0	0.38	0.13	2145	2.14	65
9.0	NR	19.9	0.64	0.17	1540	1.54	65
8.5	R	18.9	0.62	0.16	1485	1.48	65
● 8.0	NR	17.8	0.41	0.12	1900	1.90	72
● 6.5	NR	14.6	0.34	0.12	1540	1.54	65
● 6.4	NR	14.3	0.34	0.12	1485	1.48	65
● 8.0	NR	17.9	0.38	0.12	1900	1.90	72

● -- faired cable

UNJACKETED KEVLAR WITH AND WITHOUT FAIRING   7/28/75   DIAM.=.154"

SORT BY AMP, BEH, F

AMP	BEH	F	FREQ	ST	RE	VEL	TEN
0.64	NR	9.0	19.9	0.17	1540	1.54	65
0.62	R	8.5	18.9	0.16	1485	1.48	65
0.49	NR	10.6	24.5	0.17	1900	1.90	72
0.45	R	11.2	27.2	0.18	1950	1.95	72
● 0.41	NR	8.0	17.8	0.12	1900	1.90	72
0.40	NR	13.2	29.3	0.18	2145	2.14	65
0.40	NR	11.1	25.6	0.16	2000	2.01	72
0.40	N	11.6	26.8	0.17	2000	2.01	72
0.40	N	10.2	24.8	0.17	1900	1.90	72
● 0.38	NR	0.0	17.9	0.12	1900	1.90	72
● 0.38	N	9.3	21.0	0.13	2145	2.14	65
● 0.34	NR	6.5	14.6	0.12	1540	1.54	65
● 0.34	NR	6.4	14.3	0.12	1485	1.48	65
0.34	N	12.1	27.8	0.18	2000	2.01	72

● -- faired cable

UNJACKETED KEVLAR WITH AND WITHOUT FAIRING 7/28/75 DIAM.=.154"

SORT BY BEH, AMP, F

	BEH	F	AMP	FREQ	ST	RE	VEL	TEN
	R	8.5	0.62	18.9	0.16	1485	1.48	65
	R	11.2	0.45	27.2	0.18	1950	1.95	70
	NR	9.0	0.64	19.9	0.17	1540	1.54	65
	NR	10.6	0.49	24.5	0.17	1900	1.90	70
●	NR	8.7	0.41	17.8	0.12	1900	1.90	70
	NR	13.2	0.40	29.3	0.18	2145	2.14	65
	NR	11.1	0.40	25.6	0.16	2000	2.01	73
●	NR	0.0	0.38	17.9	0.12	1900	1.90	70
●	NR	6.5	0.34	14.6	0.12	1540	1.54	65
●	NR	6.4	0.34	14.3	0.12	1485	1.48	65
	N	11.6	0.40	26.5	0.17	2000	2.01	70
	N	10.8	0.40	24.8	0.17	1900	1.90	70
●	N	9.3	0.38	21.0	0.13	2145	2.14	65
	N	12.1	0.34	27.8	0.18	2000	2.01	70

● -- faired cable